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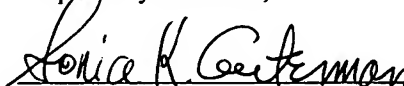
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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

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OLIGONUCLEOTIDE COMPLEX COMPOSITIONS AND METHODS OF USE AS GENE ALTERATION TOOLS			
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Oligonucleotide Complex Compositions and Methods of Use as Gene Alteration Tools

Field of invention

5 The present invention relates to the use of specific complexes of oligonucleotides and their modification products as therapeutic and/or prophylactic agents for the phenotypic and/or genotypic restoration of mutated genes, genes with inborn errors and/or for switch-on and/or switch-off of targeted gene(s).

Background of Invention

10 Numerous genetic diseases are caused by mutations in the mammalian genome. Other sources of genetic diseases are activation of silent genes or the presence of viral genes in the mammalian genome. Several types of modifications have been found to be mutated in the genome: deletion of one or several base pairs, one or several mismatches in the sequence of the
15 gene, insertion of one or several bases, or repeat triplet reiteration and absence of a whole or part of a gene.

 Genetic diseases caused by mismatches, deletion/insertion of one or several base pairs (BP) and repeat triplet mutation in the genes include: albinism, cystic fibrosis, muscular dystrophy and atrophy, sickle cell anemia, hepatic disorders, hemophilia, Crigler-Najjar
20 syndrome, renal tubular acidosis, β -thalassemia, atherosclerosis, Huntington's disease, spinocerebellar ataxia (type 1, 2 and 6), Machado-Joseph disease, myotonic dystrophy, Fragile X (forms A and B), and Frederick's ataxia [Breschel et al., Human Molec. Gen. (1997) 6, 1855-1863; Kmiec, Clin. Invest. (2003) 112, 632-636].

 Oligonucleotide complexes and their analogs have been employed as a potential
25 therapeutic for the readout of genes [McManus et al., Nat Rev Genet. (2002) 3, 737-747; Nielsen, Curr. Med. Chem. (2001) 8, 545-550; Agrawal et al., Curr. Cancer Drug Targets. (2001) 1, 197-209] and for targeted gene repair [Kmiec, Clin. Invest. (2003) 112, 632-636].

 An approach in the field of gene therapy is introduction of sequence-specific modification of the genes, using oligonucleotide complexes for the phenotypic and/or genotypic
30 restoration of defective genes. Approaches to an oligonucleotide-based strategy to achieve this goal have been tested. Chimeric RNA/DNA oligonucleotides and single-stranded

oligonucleotides were developed for site-specific correction of episomal and chromosomal target genes [Andersen et al. J Mol Med. (2002) 80, 770-81; Alexeev et al., Gene therapy (2002) 9, 1667-1675; Kmiec, Clin. Invest. (2003) 112, 632-636; Wu et al., J Biomed Sci. (2001) 8, 439-45; Yoon, PA # US1999000473872; Davis et al., PA # US1000767775; Youn et al., PA #

5 USUS2001000962628; Kmiec et al., PA # US2002000260375; Kmiec et al., PA # US2002000215432]. Experiments demonstrated the feasibility of using chimeric RNA/DNA and single stranded oligonucleotides to introduce point conversions in genes *in vitro* and *in vivo*. This gene repair approach relies on hybridization of the chimera to the target gene, generating a mismatch with the targeted point mutation. Restored gene function was anticipated to occur
10 through activation of endogenous repair systems that recognize the created mismatch [Andersen et al., J Mol Med. (2002) 80, 770-81; Alexeev et al., Gene therapy (2002) 9, 1667-1675; Kmiec, Clin. Invest. (2003) 112, 632-636; Wu et al., J Biomed Sci. (2001) 8, 439-45; Wang et al., (2003) Proc. Natl. Acad. Sci. USA 100, 14822-14827]. Double stranded oligonucleotides have been tested for site specific gene alteration in plant cells [Arntzen et al., PA # US1998000129298;
15 Kmiec, AP # US1994000353657].

Triplex forming oligonucleotides also have been employed as sequence-specific tools for gene targeting. Triplex forming oligonucleotides bind in the major groove of double stranded DNA, with high affinity. Because of this characteristic, triplex forming oligonucleotides have been proposed as tools for the site specific corrections of targeted genes [Knauert et al., Hum
20 Mol Genet. (2001) 10, 2243-2251; Richardson et al., Drug Target (2002) 10, 133-134; Thounge et al., (1993) Angewandte Chemie. Intl. Ed. Eng., 32, 666-690.].

Current targeted gene repair methods are controversial and still at the level of development, however only a very low level of repair has been found. There is a need for more effective tools, in order to obtain phenotypic or genotypic restoration of defective genes in
25 somatic tissues.

Summary

The invention features a method for targeted gene repair. Any genetic defect, e.g., a
30 substitution, deletion, or addition of at least one basepair, compared to a normal wild type sequence is phenotypically changed. In one approach, the method is carried out by contacting a

gene or gene product such as a target RNA of a cell with a hybrid DNA/RNA oligonucleotide complex and modifications of the complex. The complex contains a first strand and a second strand. The first and second strand are annealed to one another to form the complex. The first strand contains a flanking sequence that is complementary to sequence of the target RNA

5 (“hybridized ends”) and a central sequence (located between the flanking sequence) that contains at least one non-complementary nucleotide or deletion in a location opposite a defect of the target RNA. The nucleotide sequence of the first strand is complementary to the sequence of a normal wild type gene. The central sequence, which is RNase-sensitive, is at least a triplet, and is preferably at least 4, 5, 6, or more nucleotides in length. The flanking sequence of the first strand
10 includes an RNase H-resistant modification, e.g., addition of a 2-O-methyl moiety, or other modifications, to both a 3’ and 5’ to the nucleotide hybridizable to the target sequence of the gene.

In the method, the target RNA is first contacted with a phosphorothioate (PS)-containing sequence of a deoxynucleotide with RNase H resistant flanking ends and then contacted with an
15 annealed hybrid oligonucleotide complex, resulting in repairing the genetic defect.

The second strand of the complex is of the same length as the first strand, or is shorter than first strand of the complex, and the second and first strands are complementary to and annealed to one another. The complex is allowed to hybridize to target genomic RNA of the target cell, and a repaired RNA is produced in the cell. The repaired RNA contains a sequence
20 alteration opposite the defect of the target RNA, and the genomic target DNA sequence remains unaltered. The RNA alteration or phenotypic change accomplished by the method is not maintained in a progeny of the cell, i.e., is not heritable.

The flanking sequence of the first strand contains at least four complementary nucleotides (relative to the genomic target RNA) 3’ to the hybridizable sequence of the targeted gene (of the
25 target RNA and first strand RNA oligonucleotide) and at least four complementary nucleotides (relative to the genomic target DNA) 5’ to the hybridizable sequence of the targeted gene. The flanking portion of the complex sequence contains a RNase H-resistant modification, whereas the central portion of the sequence (opposite the defect) does not contain such a modification and is therefore nuclease and RNase sensitive, i.e., the nucleotide bonds in the central region are
30 enzymatically cleaved.

The first strand is at least 15 nucleotides in length. For example, the first strand contains at least about 10, 12, 14, 16, 18, 20, 30, 40, or 50 or more nucleotides, the flanking sequence of which contains at least 2 nucleotides that are complementary to target RNA in the region of the defect. The complementary flanking sequence on either side of the defect is about 5, 10, 15, 20, 25 or more nucleotides in length. The second strand of the oligonucleotide complex is at least about 7 nucleotides in length and is optionally longer, e.g., 9, 12, 15, or 20 nucleotides.

Another approach involves hybridization of a PS containing segment of a deoxyribonucleotide with RNase H resistant flanking ends, resulting in an RNase-catalyzed deletion of a small central segment of mRNA. This oligonucleotide is then washed out of the incubation medium and is replaced by a double-stranded, annealed hybrid oligonucleotide. The latter hybridizes with the targeted mRNA, and inserts an oligonucleotide segment complementary to the hybridizable oligonucleotide part of the duplex repair complex.

Nucleotide modifications are selected from the group 2'-O-methyl ribosyl; phosphorothioate; peptide nucleic acid; 2'-halo, 2'-fluoro, 2'-alkyl, 2'-alkoxylalkyl, bridged sugars and similar chemical moieties; methylphosphonate, ethylphosphonate, phosphoramidate, thiophosphate, dithiophosphate, morpholino, boronophosphate, morpholinophosphate internucleoside linkages and similar chemical moieties; derivatized heterocycles, and sugars.

Complexes are administered to a subject, e.g., a human patient, suffering from a disorder associated with a genetic defect, or to a cell obtained from a patient having a genetic disease. Cells or tissue are contacted in vivo or ex vivo. In some embodiments, the cell is an isolated cell in a culture. The method can further involve isolating and sequencing RNA from a contacted cell having a different phenotype from cells from the patient or the culture, wherein altering expression of the target gene is altering an RNA nucleotide sequence.

Brief Descriptions of the Drawings

Scheme 1 is a drawing of (A) a hypothetical scheme for repair of CFTR Δ 508 mRNA by CF4/CF6 duplex, and (B) sequences found in restored mRNA. Bold italic type corresponds to bases of 2'-O-methyl ribosyl oligonucleotides with normal internucleoside phosphate bonds (CF4 oligonucleotide). Regular type corresponds to natural RNA. Bold plus underlined type corresponds to inserted bases of ribonucleotides. Shaded bases in the CF4 and Δ 508 mRNA

indicate non-complementary Watson-Crick base pairs. Sequence analysis of RT-PCR products obtained by using different primers is also shown. (a) A in square indicates that in 7 out of 10 sequencings this A was present, but in 3 other sequencings was absent, leaving 3 deletions. (b) Dashes indicate deletions, possibly induced by PCR. (c) There are no deletions. U in square indicates that in this position U sometimes is replaced by another nucleotide.

Fig. 1. is a set of tracings of whole cell currents of $\Delta 508$ CFTR expressing cells. Top, Representative tracings of $\Delta 508$ CFTR expressing cells after treatment with CF4/CF6 were obtained before and after stimulation with a cAMP mixture. The cAMP-activated currents were inhibited by DPC (500 μ M). Bottom, Left: untreated $\Delta 508$ cells lacked a cAMP activated whole cell conductance (n=21). Center: In contrast, CF4/CF6 treated $\Delta 508$ cells had a robust cAMP response (Linear whole-cell currents were observed before and after cAMP activation). Right: cAMP activation in treated cells was inhibited by DPC. Results essentially similar to those shown were obtained when the initially used two step insertion mechanism was employed.

Fig. 2. is a set of tracings of single channel currents of $\Delta 508$ CFTR expressing cells. A. Top: representative tracing of current observed in $\Delta 508$ CFTR expressing cells after treatment with CF4/CF6. Currents were obtained in excised inside-out patches. A. Bottom: addition of PKA (100 nM) and MgATP (1 mM) induced a rapid channel activation. Data are representative of n=12 experiments. No activation was observed in control $\Delta 508$ CFTR expressing cells (data not shown). B. Top: the PKA-activated Cl^- single channel currents had a single channel conductance of 12 pS (n=6). B. Bottom: details of Cl^- single channel conductance are shown in the all-point histograms.

Fig. 3. is a set of bar graphs that show the results of an SPQ fluorescence assay. Cl^- induced changes in fluorescence were followed in cells loaded with the Cl^- sensitive dye SPQ. SPQ fluorescence was tested in WT1 cells expressing wild type CFTR, and control and treated $\Delta 508$ cells in a custom-made chamber, under UV-fluorescence microscopy. A cAMP-induced response (5-15 min) was only observed in WT1 and treated $\Delta 508$ cells (p<0.05). Numbers in parentheses indicate individual cells analyzed.

Fig. 4. is a photograph of an agarose gel electrophoretogram showing allele-specific RT-PCR analysis of CFTR mRNA. Samples from WT1 mRNA were diluted into $\Delta 508$ mRNA (lanes 2 to 14, from undiluted to 10^6 order with 10-fold serial dilutions) to test efficiency of allele-specific primers (CFFW and CFFM, Table 1). Lanes 2 and 3 show WT1 and $\Delta 508$ mRNA amplified with respective primers. The wild type primers recognized WT1 mRNA in dilutions of up to $1:10^5$ (Lanes 11 and 12). Gel electrophoresis was conducted in agarose gels (3%), and a 25 base pair (bp) ladder is shown on the left lane.

Fig. 5. is a photograph of an agarose gel electrophoretogram showing specific reverse primer analysis of mRNA in samples of RT-PCR material obtained by amplification with wild type (N1) and mutant (M1) specific reverse primers (Table 1). Lanes 1 and 2 are $\Delta 508$ untreated and RT PCR with N1 and M1 primers respectively. Similarly lanes 3 and 4 are $\Delta 508$ treated with CF4/CF6 and following RT PCR with N1 and M1 primers respectively. Gel electrophoresis was performed in 3% agarose gel.

Fig. 6. is an automated tracing by type of nucleotide base obtained from DNA sequencing of RT-PCR products. Sequence analysis of the CF4/CF6 treated $\Delta 508$ CFTR was conducted by RT-PCR analysis of total RNA. The PCR materials observed in the gel were subcloned in pCR-Blunt vector and sequenced at the MGH Sequencing Facility. Minor peaks represent background. Variations in heights of peaks are due to instrumental sensitivity

Scheme 2 is a drawing of a hypothetical site-specific deletion/insertion mechanism in the RNA containing mismatch region, with the two step nucleotide complex technique. Red corresponds to targeted nucleotide(s), black and white correspond to hybrid oligonucleotide for RNase-H activation, yellow corresponds to natural RNA, grey corresponds to template oligonucleotide in insertion/deletion duplex, and blue corresponds to inserted/repaired segment of RNA

Scheme 3 is a drawing of a hypothetical site-specific deletion/insertion mechanism in the RNA containing mismatch region, with the one step oligonucleotide complex technique. Red

corresponds to targeted nucleotide(s), yellow corresponds to natural RNA, grey corresponds to template oligonucleotide in insertion/deletion duplex, and blue corresponds to inserted/repaired segment of RNA

5 Scheme 4 is a drawing of a hypothetical site-specific deletion/insertion mechanism in the RNA containing deleted region, with the two step oligonucleotide complex technique. Black and white correspond to hybrid oligonucleotide for RNase-H activation, yellow corresponds to natural RNA , grey corresponds to template oligonucleotide in insertion/deletion duplex, and blue corresponds to inserted/repaired segment of RNA

10 Scheme 5 is a drawing of a hypothetical site-specific insertion/deletion mechanism in the RNA containing deleted region, with the one step oligonucleotide complex technique. Yellow corresponds to natural RNA, grey corresponds to template oligonucleotide in “insertion duplex”, and blue corresponds to inserted/repaired segment of RNA (or DNA).

15 Scheme 6 is a drawing of a hypothetical site-specific deletion/insertion mechanism in the RNA containing repeat mutations, with the two step oligonucleotide complex technique. Red corresponds to targeted nucleotide(s), black and white correspond to hybrid oligonucleotide for RNase-H activation, yellow corresponds to natural RNA, grey corresponds to template oligonucleotide in insertion/deletion duplex, and blue corresponds to inserted/repaired segment of RNA

20 Scheme 7 is a drawing of a hypothetical site-specific deletion/insertion mechanism in the RNA containing repeat mutations, with the one step oligonucleotide complex technique. Red corresponds to targeted nucleotide(s), yellow corresponds to natural RNA, grey corresponds to template oligonucleotide in insertion/deletion duplex, and blue corresponds to inserted/repaired segment of RNA. The XXX indicates the size of the base of the oligonucleotide loop. It may vary between zero and twenty.

25 Scheme 8 is a drawing of a hypothetical site-specific frame changing mechanism in the active RNA, with the two step oligonucleotide complex technique. Red corresponds to targeted

nucleotide(s), black and white correspond to hybrid oligonucleotide for RNase-H activation, yellow corresponds to natural RNA , grey corresponds to template oligonucleotide in insertion/deletion duplex, and blue corresponds to inserted/frame changed segment of RNA

5 Scheme 9 is a drawing of a hypothetical site-specific frame changing mechanism in the active RNA, with the one step oligonucleotide complex technique. Red corresponds to targeted nucleotide(s), yellow corresponds to natural RNA, grey corresponds to template oligonucleotide in insertion/deletion duplex, and blue corresponds to inserted/frame changed segment of RNA.

10 Scheme 10 is a drawing of a hypothetical site-specific transcription or translation start site insertion mechanism in the active RNA, with the two step oligonucleotide complex technique. Red corresponds to targeted nucleotide(s), black and white correspond to hybrid oligonucleotide for RNase-H activation, yellow corresponds to natural RNA , grey corresponds to template oligonucleotide in insertion/deletion duplex, and blue corresponds to inserted/frame
15 changed segment of RNA.

 Scheme 11 is a drawing of a hypothetical scheme for repair of Inactive tyrosinase by two step oligonucleotide complex technique. Bold italic type corresponds to natural RNA. Small caps correspond to PS ODN. Shaded corresponds 2'-o-methylribosyl oligonucleotides, with
20 internucleoside phosphate bonds. Underline base corresponds targeted base. Base in square correspond replaced base.

 Scheme 12 is a drawing of a hypothetical scheme for repair of Inactive tyrosinase by one step oligonucleotide complex technique. Bold italic type corresponds to natural RNA. Small
25 caps correspond to thiophosphate oligodeoxynucleotide. Shaded corresponds 2'-o-methylribosyl oligonucleotides, with internucleoside phosphate bonds. Underline base corresponds targeted base. Base in square correspond replaced base.

 Scheme 13 is a drawing of a hypothetical scheme for repair of Cystic Fibrosis $\Delta 508$
30 mRNA by two step oligonucleotide complex technique. Bold italic type corresponds to natural RNA. Small caps correspond to thiophosphate oligodeoxynucleotide. Shaded corresponds 2'-o-

methyribosyl oligonucleotides, with internucleoside phosphate bonds. * and _ _ _ corresponds deletion region of mutated mRNA.

Scheme 14 is a drawing of a hypothetical scheme for repair of Cystic Fibrosis $\Delta 508$ mRNA by one step oligonucleotide complex technique. Bold italic type corresponds to natural RNA. Shaded corresponds 2'-o-methyribosyl oligonucleotides, with internucleoside phosphate bonds. * and _ _ _ correspond to a deletion region of mutated mRNA.

Detailed Description

A target gene such as one associated with a disease state carries a mutation compared to the sequence of a normal wild type gene. The central segment of the oligonucleotide repair complex has a normal sequence compared to the target gene. A modification confers ribonuclease resistance. Alternatively, a modification confers induction of ribonuclease activity in the cell. At least one nucleotide of the complex is a 2'-O-methyl ribosyl nucleotide. For example, there is a plurality of 2'-O-methyl ribosyl nucleotides. The second strand can further contain a small chemical group at a 5' or 3' terminus, or the second strand further contains a small chemical group at both 5' and 3' termini. The modification can be located at a nucleotide in a 3' or a 5' terminus, or both. The second strand further comprises a modification comprising a small chemical group in a 3' or a 5' terminus. For example, the small chemical group is selected from phosphate, diphosphate, triphosphate, thiophosphate, dithiophosphate, aldehyde, carboxy, dihydroxy, hydroxyl, methyl, ethyl, sulfhydryl, sulfate, and boronate. The central segment comprises at least one modification which is a phosphorothioate.

The genetic disease is selected from the group of albinism, cystic fibrosis, muscular dystrophy, myotonic dystrophy, muscular atrophy, sickle cell anemia, hepatic disorder, hemophilia, Crigler-Najjar syndrome, renal tubular acidosis, β -thalassemia, atherosclerosis, Huntington's disease, spinocerebellar ataxia, Machado-Joseph disease, Fragile X, and Frederick's ataxia.

The oligonucleotide complex technique provided herein is a new approach to modulation of genetic diseases, including but not limited to those diseases mentioned above. The oligonucleotide complex technique provides functional restoration of the mutated genes by deletion/insertion of a segment of RNA (or DNA). The oligonucleotide complex technique

method inserts one or more deleted nucleotide(s) into the targeted region of specific RNA (or DNA). The oligonucleotide complex technique facilitates simultaneous correction of more than one mutation with a single set of oligonucleotide complex into a single targeted RNA (or DNA) gene.

5 Site-specific insertion of the specific RNA (or DNA) genes with the oligonucleotide complex technique may require one or more treatment steps with the oligonucleotide complex. Site-specific alteration of gene with the oligonucleotide complex technique may be performed in one or more targeted genes by using several oligonucleotide complex sets consecutively as required, or even simultaneously. For enhancing targeted gene repair efficiency using the oligonucleotide
10 complex technique this complex is used synergistically with other known or potential therapeutic compounds. The oligonucleotide complex technique is used for targeting one or several harmful genes one by one or simultaneously. The oligonucleotide complex technique is used for extension of translation of targeted genes (by elimination of undesirable stop codons). The oligonucleotide complex technique is used for creation of “new genes” by insertion of
15 transcription or translation sites in certain regions of the mammalian genome

 The oligonucleotide complex technique is used for deletion or insertion of purine or pyrimidine repeats at the ends of different genomic RNA or DNAs. The oligonucleotide complex technique is used for the deletion or diminution of a region of RNA containing a reiteration of excess triplets. The oligonucleotide complex technique provides insertion of UGU
20 in a sufficient fraction of $\Delta 508$ mRNA to induce phenotypic reversion in a tissue culture cell line. The oligonucleotide complex technique according to SPQ data indicates suppression of the chloride anion conductance, or in the other words phenotypic restoration of a mutated $\Delta 508$ gene. The oligonucleotide complex technique according to subcloning data presented herein shows approximately 30 percent insertion of UGU in the site of the $\Delta 508$ mRNA UUU triplet
25 deletion. The oligonucleotide complex technique is used for deletion or insertion of purine or pyrimidine repeats at the ends of specific genomic RNA or DNAs. The oligonucleotide complex technique inserts UGU in the site of the $\Delta 508$ mRNA UUU triplet deletion with one step addition of the oligonucleotide deletion/insertion hybridized RNA/modified RNA duplex. The oligonucleotide complex technique inserts UGU in the site of the $\Delta 508$ mRNA UUU triplet
30 deletion with more than one (two) step treatment. The first step treatment was performed with RNase H (or other endonucleolytic enzyme) deleting single strand RNA. The second step of the

treatment was performed by the oligonucleotide deletion/insertion RNA/modified RNA duplex. The oligonucleotide complex technique may require more than one step treatment (i.e.

consecutive steps) for the restoration of targeted RNA (DNA) gene(s). RNase H (or other endonucleolytic enzyme) deletes a specific region of RNA, plus the pre-hybridized duplex of

oligonucleotides involved in the oligonucleotide complex technique include, but are not limited to, standard oligonucleotides, modified oligonucleotides, standard and modified oligonucleotides with different sequential alteration, standard or modified oligonucleotide in the middle and flanked by different derivatives of oligonucleotides, derivatives of oligonucleotides facilitating different endonucleolytic deletions and/or some other "gene insertion/deletion"

catalysis, oligonucleotides conjugated with different chemical groups (such as, but not limited to, intercalators, groove binders, alkylating reagents, photoactive groups (such as psoraren) and other moieties).

Compositions of oligonucleotide derivatives in the oligonucleotide complex technique include, but are not limited to standard and modified oligonucleotides with different sequential

alteration. Oligonucleotide derivatives in the oligonucleotide complex technique may contain small chemical groups at the 5'- and /or 3'-end, including but not limited to, phosphate, diphosphate, triphosphate, thiophosphate, dithiophosphate, aldehyde, carboxyl, dihydroxyl, hydroxyl, methyl, ethyl, sulfhydryl, sulfate, Boronates, and similar chemical moieties.

Oligonucleotide derivatives in the oligonucleotide complex technique may include, but are not limited to PNA; 2'-halo, 2'-fluoro, 2'-alkyl, 2'-alkoxylalkyl, bridged sugars and similar chemical moieties; methylphosphonate, ethylphosphonate, phosphoramidate, thiophosphate, dithiophosphate, morpholino, Boronophosphate, morpholinophosphate internucleoside linkages and similar chemical moieties; oligonucleotides with derivatized heterocycles, sugars and/or internucleoside linkages and similar chemical moieties. Oligonucleotide derivatives in the oligonucleotide complex technique may include, but are not limited only to derivatized heterocycles, sugars or internucleoside linkages, but also to combination of these moieties mentioned above.

RNase H- (or other endonucleolytic enzyme-) activating single stranded oligonucleotide and pre-hybridized duplex of oligonucleotides involved in the oligonucleotide complex technique method may be four or more (up to three hundred) base long. The deletion/insertion oligonucleotide duplex used in the oligonucleotide complex technique method may be composed

of oligonucleotides of different length. The deletion/insertion oligonucleotide duplex employed in the oligonucleotide complex technique may possess the 5'- and/or 3'- "sticky ends". The length of "the sticky ends" in the deletion/insertion oligonucleotide duplex employed in the oligonucleotide complex technique may be one base and more (up to 40-60 bases). The double strand part of the deletion/insertion oligonucleotide duplex employed in the oligonucleotide complex technique may be 4-5 base pairs or more (up to 100 base pairs).

Sources of the derivatives of oligonucleotide used in the oligonucleotide complex technique method are chemically or biologically synthesized. The oligonucleotide complex technique is also useful to target with an oligonucleotide sequence specifically the deletion or insertion of a portion of a gene from a pathogenic bacterium, virus, insect, arthropod, parasite, land or marine plant or other living organism; to silence a virulence factor, thereby rendering that organism into a non-pathogenic one. This technique is used for preparation of a vaccine against the pathogen, or a therapeutic treatment by spray or other means of obtaining entry to the pathogen.

The oligonucleotide complex technique is used for the suppression/inactivation of biological pathogens in body fluids either *in vitro* or *in vivo*. The oligonucleotide complex technique is used for diagnostic analytical purposes or as a tool for a laboratory research.

Cystic Fibrosis – Related Gene Defects

Data herein show oligonucleotide complex compounds and methods for the TGR and restoration of a cystic fibrosis phenotype in a cultured $\Delta 508$ CFTR cell line, using hybrid oligonucleotides and a special modified chimera of an RNA/RNA (DNA) duplex.

Cystic Fibrosis (CF) is a lethal disorder caused by mutations in the CFTR gene encoding the CFTR channel [Riordan, et al., J.R., (1989) Science, 245, 1066-1073; Kerem et al., (1989) Science, 245, 1073-1080]; Burke (2003), Eng. J. Med. 349, 969-974]. CFTR, a cAMP- activated anion channel [Anderson et al., (1991) Science, 251, 679-682; Bear et al., (1992) Cell, 68, 809-818], is associated with the dysfunctionality of epithelia in several tissues [Crawford et al., (1991) Proc. Natl. Acad. Sci. USA 88, 9262-9266] including lungs, pancreas, intestine, sweat glands and kidneys. CF is the most common lethal genetic disease of Caucasians, affecting 1 in

2000 individuals. More than 150 mutations have been identified in the CFTR gene [Tsui, (1992) Trends Genet. 8, 391-398], associated with a pleiotropic spectrum of CF phenotypes [Cutting, (1993), J. Bioenerg. Biomembr. 25, 7-10; Strandvik et al., (2001), Genet. Test. 5, 235-242]. New mutations have been found with distinctive impacts on CF populations [Gilfillan et al., (1998), J. Med. Genet. 35, 122-125; Onay et al., (1998), Hum. Genet. 102, 224-230; Visich et al., (2002), Clin. Genet. 61, 207-213]. However, the most frequent CFTR mutation, accounting for almost 75% of all cases of the disease, is a deletion of three bases (TTT), encoding the amino acid phenylalanine in position 508 of the translation sequence, accompanied by C to U replacement immediately 5' to the deletion. This deletion is often accompanied by a mismatch immediately adjacent in the 5' direction to the deletion: in a U in place of a C.

The $\Delta 508$ CFTR is a misfolded but partially functional channel protein [Li et al., (1993) Nature Genet. 3, 311-316; Pasyk et al., (1995) J. Biol. Chem. 270, 12347-12350], unable to translocate perfectly to target plasma membranes [Denning et al., (1992) Nature, 358, 761-764; Cheng et al., (1990), Cell, 63, 827-834]. Several chemical and pharmacological strategies have been attempted, to rescue the CF phenotype at the cellular level, to bring $\Delta 508$ CFTR to the plasma membrane. Partial success has also been achieved by adenoviral vector infection [Boucher et al., (1994), Hum. Gene Ther. 5, 615-639; Teramoto et al., (1998), J. Virol. 72, 8904-8912] and re-insertion of the wild type CFTR gene into a CF genetic background. More recently, a novel repair strategy was used, based on trans-splicing of the $\Delta 508$ CFTR pre-mRNA [Liu et al., (2002), Biotechnol. 20, 47-52; Puttaraju et al., (2001), Mol. Ther. 4, 105-114; Mansfield et al., (2000) Gene Ther. 7, 1885-1895]. Gentamycin has also been found to induce a correction of faulty CFTR function in CF, caused by CFTR stop mutations [Bedwell et al., (1997) Nature Med., 3, 1280-1284], rather than by the TTT deletion.

Loss or suppression of disease-associated gene function by antisense oligonucleotide technologies involves specific inhibition of DNA, RNA and protein expression [Zamecnik et al., (1978), Proc. Natl. Acad. Sci. USA 74, 280-284; Stephenson et al., (1978) Proc. Natl. Acad. Sci. USA 75, 285-288]. This is based in good part on complementary hybridization of synthetic oligonucleotides with the natural sequences in either DNA or RNA [Temsamani et al., (1994) Antisense Res. Devel. 4, 279-284]. Triplex-forming oligonucleotides have also been used for the modification of cellular gene function [Felsenfeld et al., (1957) J. Am. Chem. Soc., 79, 2023-2024; Thoung et al., (1993) Angewandte Chemie. Intl. Ed. Eng., 32, 666-690; Agrawal et al.,

(1990). Proc. Natl. Acad. Sci. USA 87, 1401-1405]. The consequence of such interaction is a competitive blockade of either DNA or RNA synthesis at replication or transcription, respectively and, in the case of exons, at the translational steps in protein synthesis. Upon cell entry, exogenous complementary deoxyoligonucleotides hybridize with a target mRNA, inducing an excision endonucleolytic effect on the mRNA, a so-called ribonuclease H (RNase H) effect . resulting in synergism with hybridization inhibition [Zamecnik et al., (1996) Ed. By Sudhir Agrawal, Humana Press, NJ, 1-11]. Likewise, RNA editing [Simpson et al., (1996) Annu. Rev. Neurosci. 19, 27-52] has been reported in numerous cell systems where nucleotide sequences can also be modified at the RNA level. RNA editing encompasses various mechanisms, including base substitutions and deletions [Simpson et al., (1996) Annu. Rev. Neurosci. 19, 27-52]. RNA duplexes with internal and external guide sequences in some cases are required to drive these reactions.

Double stranded RNA sequences have a role in RNA interference (RNAi) and gene silencing at the transcriptional level [Hannon, (2002) Nature, 418, 244-251]. RNAi mediated gene silencing was discovered in *C. elegans* [Fire et al., (1998), Nature, 391, 806-811; Montgomery et al., (1998), Proc. Natl. Acad. Sci. USA 95, 15502-15507; Grishok et al., (2000), Science, 287, 2494-2497], and has been observed in numerous cell models and organisms [Hannon, (2002) Nature, 418, 244-251; Hammond et al., (2000), Nature, 404, 293-296; Silva et al., (2002), Trends Mol. Med. 8, 505-508. Gene silencing results from successive cleavage of long dsRNA, particularly originating from viruses, to oligonucleotide siRNAs by DICER enzymes [Zamore et al., (2000) Cell, 101, 25-33; Bernstein et al., (2001), Nature, 409, 363-366]. After oligonucleotide hybridization of siRNA with mRNA, the cleavage of target mRNA is catalyzed [Hammond et al., (2000), Nature, 404, 293-296; Zamore et al., (2000) Cell, 101, 25-33]. RNAi phenomena have been used for target gene silencing from nematodes and plants to mammals [Hannon, (2002) Nature, 418, 244-251]. Separate from the above is CpG stimulation of host immunomodulatory mechanisms, in both prokaryotic and eukaryotic organisms [Krieg (2003) Nat. Med., 9, 831-835; Kandimalla et al., (2003) Biochemical Society Transactions, 31, 654-658].

The gain of function and/or correction of defective genes present a continuing challenge for gene therapy. Partial restoration of function in the $\Delta 508$ CFTR background has been shown to occur by membrane insertion of $\Delta 508$ CFTR without changes in either phenotype or genotype

[Brown et al., (1996) *Cell Stress & Chaperones*, 1, 117-125; Arispe et al., (1998) *J. Biol. Chem.* 273, 5727-5744]. This is based on the capacity of $\Delta 508$ CFTR to function even as a misfolded protein [Welsh et al., (1993), *Cell*, 73, 1251-1254; Ward et al., (1994), *J. Biol. Chem.* 269, 25710-25718]. Its translocation to a plasma membrane may incompletely restore functionality of the phenotype RNA/DNA oligonucleotide hybrids [Cole-Strauss et al., (1996), *Science*, 273, 1386-1389; Yoon et al., (1996), *Proc. Natl. Acad. Sci. USA* 93, 2071-2076; Alexeev et al., (1998), *Nature Biotech.* 15, 1343-1346; Parekh-Olmedo et al., (2001), *Sci. STKE* 73, PL1] and single stranded oligonucleotides [Igoucheva et al., (2001) *Gene Therapy*, 8, 391-399] have been used for the correction of defective genes. Substituted, circular, single stranded RNA/DNA chimeras have been employed to insert base pairs in deficient genomic DNA [Cole-Strauss et al., (1996), *Science*, 273, 1386-1389; Yoon et al., (1996), *Proc. Natl. Acad. Sci. USA* 93, 2071-2076]. In these studies, nucleotide exchange of target episomic and genomic DNA was reported using chimeric RNA/DNA oligonucleotides. Some attempts at replicating this work, however, showed no nucleotide exchange in the targeted loci by cloning of the PCR products [Zhang et al., (1998) *Antisense & Nucleic Acid Drug Developm.* 8, 531-536]. Results were viewed by these and other investigators as PCR artifacts created by the RNA/DNA oligonucleotides themselves [Zhang et al., (1998) *Antisense & Nucleic Acid Drug Developm.* 8, 531-536; Taubes, (2002) *Science*, 298, 2116-2120]. Transcriptional repair has been used for repair of mRNA. Spliceosome mediated cis-splicing of pre-mRNA is an essential step in gene expression [Jurica et al., (2003), *Mol. Cell*, 12, 5-14]. Other trans-splicing mechanisms in pre-mRNA molecules have been shown to form functional hybrid mRNA molecules in different mammalian systems [Spector, (1993), *Curr. Opin. Cell Biol.* 5, 442-447; Harris et al., (1990), *Nucleic Acids Res.* 18, 3015-3019]. Spliceosome mediated RNA transplicing (SmaRT) technology has also been used to modify $\Delta 508$ CFTR transcripts in human CF airway epithelia [Liu et al., (2002), *Biotechnol.* 20, 47-52].

An mRNA hybridized to a single stranded synthetic short piece of DNA was used to activate RNase H [Agrawal et al., (1990). *Proc. Natl. Acad. Sci. USA* 87, 1401-1405], which then specifically hydrolyzed only the hybridized segment of mRNA. RNase H as an ubiquitous enzyme had been previously known [[Agrawal et al., (1990). *Proc. Natl. Acad. Sci. USA* 87, 1401-1405]]. This work, and others define nucleotide limits of RNase H activity in a precise way. At least a 4-6 nucleotide internally located region in an mRNA, which is hybridized to a

phosphorothioate modified (PS) oligodeoxyribonucleotide, is needed for RNase-mediated excision. If a precise small segment of mRNA, which included the deleted UUU region (the ribosomal substitute for TTT) were synthesized and annealed to the larger chimera, which induced/activated a small deletion in mRNA, an insertion of the somewhat larger total piece excised might restore the phenotypic effect at the mRNA level.

Initially, a modified oligodeoxyribonucleotide with a central segment containing a phosphorothioate (PS) modification was constructed, with flanking segments PS plus 2'-O-methyl modifications. This was designed to hybridize in Watson-Crick base complementarity to the region of $\Delta 508$ mRNA where the PS section would be directly opposite the $\Delta 508$ mRNA position, flanked 3'- and 5'- by an adjacent few nucleotides complementary to the $\Delta 508$ mRNA. In this way the PS segment would activate endogenous RNase H, and cleave those bases opposite the PS complementary oligonucleotide. The 2'-O-methyl PS, plus segments on both sides of the RNase H sensitive section would be generally nuclease and RNase H resistant and would serve in this way as a "genetic band aid". Without being limited by any particular mechanism, the flanking segments are intended to hold the 5'- and 3'- segments of $\Delta 508$ mRNA in place, in position for a possible insertion or repair of bases in a second step. For the possible repair step two single complementary strand oligonucleotides were constructed: Cystic Fibrosis 4 (CF4) and Cystic Fibrosis 6 (CF6), as shown in Scheme 1. This combination was annealed to form a duplex. The duplex was added to growing $\Delta 508$ CFTR cell cultures. Patch clamp examination [Reisin et al., (1994) J. Biol. Chem. 269, 20584-20591] showed evidence of phenotypic reversion (Figures 1 and 2). When the CF4/CF6 annealed duplex without oligonucleotide treatment, as described above, was, however, added to the tissue culture cells, phenotypic reversion was likewise found, based on the patch clamp technique. A one step phenotypic reversion technique was chosen, as a simpler model for the sequencing studies described below.

CF4 and CF6 were annealed to form an oligonucleotide duplex (CF4/CF6) (Table 1) and were then added to the $\Delta 508$ cells in tissue culture. There was restoration of the CFTR channel to functional normality, as determined by patch clamping and 6-methoxy-N-(3-sulfopropyl)quinolinium (SPQ) quenching techniques. Under those conditions, restoration of function was found to occur in 8-18 hours (Figures 1 and 2). As 2'-O-methyl modified CF4 has been reported not to activate RNase H [Shen et al., (1998) Bioorg. Med. Chem., 6, 1695-1705],

there would appear to be another endonucleolytic enzyme responsible for the base excision, unless RNase H is activated by a triple-stranded oligonucleotide, in which the complementary 2'-O-methyl moiety is present.

Under Rose experimental conditions there was complete restoration of CFTR function, whereas non-insertion reversion have been only partial. [Rose D M et al, Eur J Res 2000;5, 9-12] On replication of the human tissue culture cells and washing out of the oligonucleotide after a few days incubation, the restoration of CFTR function was lost. This strongly indicated a phenotypic but not genotypic (i.e. RNA but not DNA) restoration of functionality of the CFTR channel. Amplification and sequencing technology was used to determine whether trinucleotide insertion into $\Delta 508$ mRNA has been made. Scheme 1 is a schematic diagram of the proposed insertional mechanism.

An oligonucleotide complex (CF4/CF6, respectively 2'-O-methyl RNA/unmodified RNA oligonucleotide duplex) was used herein to restore CFTR function by insertion of missing bases in $\Delta 508$ CFTR mRNA from a cultured ($\Delta 508$) cell line. Cyclic AMP-activated (cAMP) whole cell currents and Cl^- transport were detected in CF4/CF6 treated, rather than control $\Delta 508$ cells by the patch clamping and by SPQ fluorescence quenching analysis, respectively. Further, the nucleotide addition in the deleted region of $\Delta 508$ CFTR was determined after amplification by the Reverse Transcriptase-Polymerase Chain Reaction (RT-PCR). Insertion of UGU and replacement of U by C immediately 5' to the deletion site in $\Delta 508$ mRNA appear to have taken place, with phenotypic but not genotypic reversion in tissue culture of treated cells. The mechanism of insertion of nucleotides is yet to be determined.

The examples provided herein demonstrate feasibility of using an oligonucleotide complex technique as a therapeutic and/or prophylactic agent for the phenotypic and restoration of function of a mutated gene. The invention having now been fully described, it is exemplified by the following examples and claims, which are not to be construed as further limiting. The contents of all references cited are incorporated in their entireties herein by reference.

EXAMPLES

Oligonucleotide complexes and methods for their use for the functional restoration of the mutated genes by deletion/insertion mechanism of the segment of RNA are provided.

Several genetic diseases relate to disorders in the sequences of mutated genes and genes with inborn errors. Other major sources of genetic diseases, shown above, are due to “switch on” silent genes or presence of viral genes in the mammalian genome.

The cause of a fatal or serious genetic disease may be as small as a single mismatch in base pair (one mismatch, one inserted/deleted base pair in the whole gene sequence) or absence of a partial or whole gene in the genome. Consequently, availability of the highly specific oligonucleotide complex technique for the restoration of the targeted (defected) gene could be a powerful tool to combat currently incurable genetic diseases.

Site-specific insertion of the genes with the oligonucleotide complex technique (as shown herein as replacement of a cystic fibrosis phenotype in a cultured $\Delta 508$ CFTR cell line experiments) can occur with a one or two step oligonucleotide complex treatment. Below are shown schemes for restoration of mutated and inborn error genes (Schemes 2-7), and schemes of switch-on and/or switch-off targeted genes (Schemes 8-10) using an oligonucleotide complex technique.

One step and two step oligonucleotide complex treatment of targeted RNA (or DNA) are shown in the Schemes 3, 5, 7, 9 and 2, 4, 6, 8, 10 respectively.

In Scheme 2 is shown a hypothetical site-specific deletion/insertion mechanism at the targeted region of RNA with the two step oligonucleotide complex technique. The targeted region in this case could be one (or a few) mismatched bases or one (or a few) inserted bases in the RNA sequence. On the first step, oligonucleotide for RNase-H activation deletes the target region of RNA, and on the second step insertion of the desirable sequence takes place. The RNase H deleted region could be a few or more bases, depending on the extend of RNase induced deletion, as a result of which the RNA oligonucleotide from the insertion duplex might be spliced into the deleted region, or alternatively serve as a triplex backbone sequence for a one-by-one insertion mechanism.

In Scheme 3 is shown site-specific deletion/insertion mechanism of the targeted region of RNA with the one step oligonucleotide complex technique. There are different possibilities of one step restoration: triplex backbone sequence formation by a one-by-one insertion mechanism, with specific docking and cleavage of selective nucleotide sequences which are hybridized to an RNA (or DNA) sequence. The cleavage might be induced by either a new enzyme or the Dicer enzyme, and as a result, production of RNA (or DNA) with a corrected (inserted) region.

In Scheme 4 is shown site-specific insertion mechanism of the deleted region of RNA with the two step oligonucleotide complex technique. In schemes 6, 8 and 10 are shown the hypothetical site-specific insertion/deletion mechanism at the targeted regions of RNA (or DNA) with the two step oligonucleotide complex technique. RNA (such as Huntington's disease) in Scheme 6 contains reiteration of excess triplets, and accordingly the purpose of the deletion step is to cut out the excess repeats. RNA shown in Scheme 8 is a model of active (harmful) RNAs and the goal of the insertion is to switch off these RNAs. The purpose of the insertion shown in Scheme 10 (opposite of Scheme 8) is to "wake up" a silent gene or to create new one. The insertion shown in Schemes 2, 4, 6, 8 and 10 could proceed with similar mechanisms, but goals achieved for each of the approach would be different.

The purpose of the approaches shown in Schemes 5, 7 and 9 is identical to the Schemes 4, 6 and 8. The deletion/insertion mechanism of the targeted region of RNA, shown on Schemes 5, 7 and 9, proceeds with the one step oligonucleotide complex technique, as described for Scheme 3.

In Schemes 11 and 12 are shown schemes for repair of an inactive tyrosinase gene by one and two step oligonucleotide complex approaches, respectively. The schemes contain one of the possible versions of the oligonucleotide complex which may be used for the replacement of mutated C with G in inactive tyrosinase mRNA. This type of alteration could achieve a phenotypic restoration of the mutated tyrosinase gene.

In Schemes 13 and 14 are shown schemes for repair of Cystic Fibrosis $\Delta 508$ mRNA by one and two step oligonucleotide complex treatment approach. As was described herein, mutated $\Delta 508$ mRNA contains two defects: first, absence of a UUU triplet at $\Delta 508$ region and change of U to a C immediately 5' to the same $\Delta 508$ position. Because of the close location of both mutations one set of oligonucleotide complex was sufficient for repair of both defects.

In some cases the targeted gene might contain more than one mismatch or inserted (deleted) region, which may be distantly located. For restoration of such genes it would be appropriate to use two or more oligonucleotide complex sets consecutively or simultaneously.

For enhancing targeted gene repair efficiency of oligonucleotide complex, they could be used synergistically with other known or potential therapeutic compounds.

The Examples herein show use of oligonucleotide complex compounds and methods for the restoration of a cystic fibrosis phenotype in a cultured $\Delta 508$ CFTR cell line using hybrid oligonucleotide and a modified chimera of an RNA/RNA (DNA) duplex.

Loss or suppression of deleterious gene function by antisense oligonucleotide technologies involves specific inhibition of DNA and RNA synthesis and protein expression [Zamecnik et al., (1978), Proc. Natl. Acad. Sci. USA 74, 280-284; Stephenson et al., (1978) Proc. Natl. Acad. Sci. USA 75, 285-288]. Upon cell entry, exogenous complementary deoxyoligonucleotides hybridize with a target mRNA, inducing an excision endonucleolytic effect on the mRNA, due to activation of ribonuclease H (RNase H) [Agrawal et al., (1990). Proc. Natl. Acad. Sci. USA 87, 1401-1405.], resulting in synergism with hybridization inhibition [Zamecnik et al., (1978), Proc. Natl. Acad. Sci. USA 74, 280-284; Zamecnik et al., (1996) Ed. By Sudhir Agrawal, Humana Press, NJ, 1-11]. Triplex-forming oligonucleotides have also been used to modify gene function [Felsenfeld et al., (1957) J. Am. Chem. Soc., 79, 2023-2024; Thoung et al., (1993) Angewandte Chemie. Intl. Ed. Eng., 32, 666-690]. Likewise, RNA editing [Simpson et al., (1996) Annu. Rev. Neurosci. 19, 27-52] has been reported in numerous cell systems where nucleotide sequences can also be modified at the RNA level. Other mechanisms may apply to dsRNA sequences if introduced into biological systems. This is the focus of current attention for their role in RNA interference (RNAi) and gene silencing at the transcriptional level [Hannon, (2002) Nature, 418, 244-251]. RNAi mediated gene silencing was discovered in *C. elegans* [Fire et al., (1998) Nature, 391, 806-811], and also found in plants and mammals [Zamore et al., (2000) Cell, 101, 25-33]. Gene silencing results from the successive cleavage of long dsRNA to oligonucleotide small interfering RNAs (siRNAs) by DICER enzymes [Zamore et al., (2000) Cell, 101, 25-33]. After oligonucleotide hybridization of siRNA with mRNA, a common feature shared with antisense DNA or RNA, the cleavage of target mRNA is catalyzed by an enzyme different from RNase H [Zamore et al., (2000) Cell, 101, 25-33]. Separate from the above is CpG stimulation of the host immuno-modulatory mechanisms, which has inhibitory implications in both prokaryotic and eukaryotic organisms [Krieg (2003) Nat. Med., 9, 831-835; Kandimalla et al., (2003) Biochemical Society Transactions, 31, 654-658].

Gain of function and/or correction of defective genes present a further challenge for gene therapy. Partial restoration of $\Delta 508$ CFTR function may be induced by membrane insertion of the mutated channel without changes in either phenotype or genotype [Brown et al., (1996) Cell

Stress & Chaperones, 1, 117-125; Arispe et al., (1998) J. Biol. Chem. 273, 5727-3574].

RNA/DNA oligonucleotide hybrids [Yoon et al., (1996) Proc. Natl. Acad. Sci. USA 93, 2071-2076 ; Parekh-Olmedo et al., (2001) Sci. STKE 73, PL1] and single-stranded oligonucleotides [Igoucheva et al., (2001) Gene Therapy, 8, 391-399] have also been used for correction of

5 defective genes. Substituted, circular or single stranded RNA/DNA chimeras have been employed to insert base pairs in deficient genomic DNA [Yoon et al., (1996) Proc. Natl. Acad. Sci. USA 93, 2071-2076 ; Parekh-Olmedo et al., (2001) Sci. STKE 73, PL1]. Some attempts at replicating this work, however, showed no nucleotide exchange in the targeted loci by cloning of the PCR products [Zhang et al., (1998) Antisense & Nucleic Acid Drug Developm. 8, 531-536],
10 and these results were viewed as PCR artifacts created by the RNA/DNA oligonucleotides themselves [Zhang et al., (1998) Antisense & Nucleic Acid Drug Developm. 8, 531-536; Taubes, (2002) Science, 298, 2116-2120]. Transcriptional repair is also the focus of recent attention in the repair of mRNA. Spliceosome mediated RNA transplicing (SmaRT) technology has been used to modify $\Delta 508$ CFTR transcripts in human CF airway epithelia [Liu et al., (2002) Nat.
15 Biotechnol. 20, 47-52].

We previously observed, as well as others, that mRNA, hybridized to a single stranded synthetic short piece of DNA, activates RNase H, a ubiquitous enzyme that hydrolyzes specifically the hybridized segment of mRNA [Agrawal et al., (1990). Proc. Natl. Acad. Sci. USA 87, 1401-1405]. At least a 4-5 nucleotide internally located region, hybridized to a
20 phosphorothioate modified (PS) oligodeoxyribonucleotide, is needed for the excision [Agrawal et al., (1990). Proc. Natl. Acad. Sci. USA 87, 1401-1405].

In this report, single complementary strand oligonucleotides were constructed and annealed to form a duplex. Duplexes were added to growing $\Delta 508$ CFTR cell cultures, and patch clamping studies [Reisin et al., (1994) J. Biol. Chem. 269, 20584-20591] showed evidence of
25 phenotypic reversion of cells to a normal phenotype, namely cAMP-activated anion currents. Phenotypic recovery was confirmed by protein kinase A (PKA)-activated single channel currents and SPQ Cl^- fluorescence. Nucleotide treated cells contained an insertion of missing bases in the CFTR mRNA. The mechanism of insertion into mRNA is still under investigation.

The following Material and Methods were used throughout the Examples.

Synthesis of oligonucleotides.

DNA and RNA oligonucleotides (Table 1) were synthesized on a 394 DNA/RNA synthesizer (Applied Biosystems) with phosphoramidite chemistry and standard phosphoramidite monomers from Glen Research. For the introduction of 3' and 5' phosphate groups on the CF4 oligonucleotide (Table 1), 5'- and 3'-phosphorylation reagents were used accordingly (Glen Research). Phosphorothioate bonds were introduced by sulfurization with Beaucage thiolating reagent [Padmapriya et al., (1994) Antisense Res. Dev. 4, 185-199]. 2'-O-methyl modifications, oligoribonucleotides and phosphorothioate oligonucleotides were synthesized, and HPLC purified as described [Metlev et al., (1994) Bioorg. Med. Chem. Lett. 4, 2929-2934; Agrawal et al., (1998) Antisense Nucleic Acid Drug Dev. 8, 135-139].

Annealing of CF4/CF6 oligonucleotide duplex.

Stock solutions of CF4 (1mM) and CF6 (1mM) were prepared by dissolving compounds in high ionic strength buffer (0.2 M NaCl, 20 mM MgCl₂, 20 mM Tris-HCl, pH 7.0). Duplex formation was prepared with 1:1 (v:v) mixture of compounds, by heating to 75-80°C, and cooling down gradually to room temperature. All duplexes and compounds were sterilized by passage through 0.45 µm cellulose acetate centrifuge filters (Costar).

Cell culture and incubation procedures.

Mouse mammary carcinoma cells (c127i) transfected with human epithelial CFTR wild type (WT1) or Δ508 CFTR cells [Cantiello et al., (1994), J. Biol. Chem. 269, 11224-11232; Dehecchi et al., (1993) J. Biol. Chem. 268, 11321-11325] were used for these studies. The transfected c127i cells are high level producers of Δ508 CFTR mRNA. Cells were grown and maintained in Dulbecco's medium (DMEM), supplemented with 10% fetal bovine serum and 1% L-glutamine, as previously reported [Verkman, (1990) Am. J. Physiol. 259, C375-C388].

Electrophysiology and chemicals.

Whole-cell and excised inside-out patches were obtained to assess cAMP-PKA dependent anion currents in treated Δ508 cells. Currents and command voltages were obtained and driven, respectively, with a Dagan 3900 amplifier using a 1 gigaohm headstage. The excised patch-clamp configuration was carried out as previously described [Reisin et al., (1994) J. Biol. Chem. 269, 20584-20591]. Single channel data were obtained between ±100 mV in symmetrical

Cl⁻. Data were further analyzed as previously described [Reisin et al., (1994) J. Biol. Chem. 269, 20584-20591]. The pipette and bathing solution contained, in mmol/L, either: NaCl 140, MgCl₂ 1.0, KCl 5, and N-2-hydroxyethylpiperazine *N'*-2-ethanesulfonic acid (HEPES) 10, at pH 7.4, or MgCl₂ 70, HEPES 10, pH 7.4. The bathing solution also contained 1.0 mmol/L CaCl₂. Whenever indicated, the patch-pipette was filled up to at least one third of its height with either MgATP or TrisATP (100 mmol/L, pH 7.4 adjusted with N-methyl-glucamine) as previously reported [Reisin et al., (1994) J. Biol. Chem. 269, 20584-20591]. Experiments were conducted at room temperature. The cAMP stimulatory mixture contained 8-Br-cAMP, isobutyl-methyl-xanthine (IBMX) and forskolin. Final concentrations were 500 μmol/L, 200 mol/L, and 10 μmol/L, respectively. The catalytic subunit of PKA was used at a final concentration of 20 μg/ml. The Cl⁻ channel blocker, diphenylamine-2-carboxylate (DPC) was kept in a 100-fold stock solution (20 mmol/L) in 50 % water/ethanol. DPC was used at a final concentration of 500 μM.

SPQ fluorescence technique.

Cyclic-AMP-stimulated Cl⁻ transport was also followed by fluorescence changes of cells loaded with the Cl⁻ sensitive dye 6-methoxy-N-(3-sulfopropyl)quinolinium (SPQ) [Verkman, (1990) Am. J. Physiol. 259, C375-C388]. Briefly, cells were grown to partial confluence on glass coverslips. SPQ cell loading was conducted by a 5-min incubation in a Cl⁻ free diluted salt solution containing SPQ (5 mM). The saline solution contained 135 mM Na⁺-gluconate, 2.0 mM KH₂PO₄, 1.0 mM MgSO₄, 1.0 mM Ca²⁺-gluconate, and 10 mM HEPES (pH 7.4). In some experiments, gluconate was replaced by either isethionate or aspartate with similar results. SPQ fluorescence was determined under an oil immersion X20 objective in a Nikon E-800 fluorescence microscope (Tokyo, Japan), with an UV filter (96101C UV-2E/C). Images were captured with a Hamamatsu (C4742-95) digital camera and stored as TIFF files in a Macintosh computer with the IPLab Spectrum software (Signal Analysis Corp.). Pictures were analyzed digitally with the NIH Image 1.62b7 software. SPQ cytoplasmic fluorescence values were normalized between intra-nuclear (considered as zero quenching, i.e. low Cl⁻), and extracellular background. Data were expressed as percent fluorescence with respect to time zero, the time when cells were placed in an isotonic saline solution. The solution contained 135 mM NaCl, 2.0 mM KH₂PO₄, 1.0 mM MgSO₄, 1.0 mM Ca²⁺-gluconate, 10 mM HEPES (pH 7.4), with or without the cAMP stimulatory combination mixture.

Primers and RT-PCR of Δ508CFTR mRNA.

Total RNA isolated by Trizol[®] reagent according to the manufacturer's protocol (Invitrogen, CA) from either WT1 or Δ 508 cells treated with or without CF6/CF4 annealed duplex oligonucleotides (final concentration of duplex in reaction mixture 10 μ M) was used to perform the RT-PCR assay [Kleppe et al., (1971) J. Mol. Biol. 56, 341-361] in two steps by using a ThermoScript RT-PCR system (GIBCO, BRL). Several sets of primers were used (see CF Table 1). In the first step, total RNA (~ 2 μ g) was incubated for 60 min at 55°C with amplification refractory mutation system (ARMS) [Ferrie et al., (1992) Am. J. Hum. Genet. 51, 251-262] reverse mutant (M1) and normal (N1) primers (0.5 μ g each) separately for the first-strand synthesis. In a second step, after heating at 94°C for 5 min, 35 cycles of PCR were carried out on the samples. PCR cycles were performed first by denaturation at 94°C for 2 min, annealing at 62°C for 1 min, and extension at 72°C for 2 min, followed by a final extension for 10 min at 72°C. Two ARMS reverse primers (N1 and M1) [Ferrie et al., (1992) Am. J. Hum. Genet. 51, 251-262], and a forward (F1) primer were used (Table 1). Similarly RT-PCR was performed with ARMS PS reverse primer (SCFR) and PS forward primer (SNF1, Table1). RT-PCR products were separated in 3% agarose gel and subjected to automated DNA sequence analysis.

Similarly, RT-PCR was conducted using allele specific primers (Scheme 1B, Table 1) as follows. In the first step, total RNA (~2 μ g) was incubated for 60 min at 55°C with reverse (CFR) primer (0.5 μ g each) for the first-strand synthesis. In a second step, samples were heated at 94°C for 1 min. PCR was performed for thirty cycles at 60°C including denaturation at 94°C (45 sec), annealing at 60°C (45 sec), and extension at 72°C for 1 min. This procedure was ended with a seven-minute final extension at 72°C. Two forward primers (CFW and CFM) and one reverse primer (CFR) were used for allele specific RT-PCR (Table 1). The RT-PCR assay was performed with the MasterAmp[™]RT-PCR system (Epicentre, WI). In this procedure, combined reverse transcription and PCR were performed in the presence of forward normal (NF1) and mutant (MF2) and reverse (CFR) primers (0.5 μ g each) separately. First, samples were incubated for 20 min at 60°C. PCR was performed for 40 cycles at 94°C, denaturation for 30 sec, annealing at 62°C for 30 sec and 72°C extension for 1 min. The reaction ended by a final extension for 6 min at 72°C. Two forward primers (NF1 and MF2) and a reverse primer (CFR) were used for this procedure. RT-PCR products were separated in a 3% agarose gel and were then subjected to automated DNA sequence analysis. ThermoScript RT-PCR products obtained by ARMS primers

were subcloned for further separation and purification of possible heterogeneity of oligomers so obtained in pCR-Blunt vector, according to the manufacturer's protocol (Invitrogen, CA). The resulting clones were subjected to automated DNA sequence analysis using a T7 promoter primer.

5

Example 1. Restoration of $\Delta 508$ CFTR phenotype.

To restore the normal (wild type) phenotype in cells expressing $\Delta 508$ CFTR, modified oligonucleotides were constructed and their effect on ion transport was assessed in $\Delta 508$ cells treated with these constructs. In a first step, a modified oligodeoxyribonucleotide was
10 synthesized, containing phosphorothioate (PS) and PS plus 2'-O-methyl modifications for the central and flanking segments, respectively. This oligonucleotide was designed to hybridize in Watson-Crick base complementarity to the region of $\Delta 508$ mRNA where the PS section would be directly opposite the $\Delta 508$ mRNA position, flanked 3'- and 5'- by adjacent nucleotides complementary to the $\Delta 508$ mRNA. Accordingly, the PS segment would activate endogenous
15 RNase H, and cleave those bases opposite the PS complementary oligonucleotide (10 μ M). The insertion of bases then occurs in a second step.

For the second or insertion step, two complementary single strand oligonucleotides, CF4 and CF6 (Table 1, Scheme 1A) were constructed. The annealed CF4/CF6 duplex (10 μ M final concentration) was added to the $\Delta 508$ CFTR cells after 2 hours incubation, then washout, in the
20 deletion step. Next, following overnight or up to 72 hour incubation in the second (insertion) step, patch clamp examination was conducted on the treated cells.

Whole cell currents of two step treated $\Delta 508$ cells (Fig. 1) showed a 243% increase after cAMP stimulation (2.98 ± 0.68 nS/Cell vs. 0.87 ± 0.16 nS/Cell, $n=24$, $p<0.01$), which was absent in the control $\Delta 508$ cells (Fig. 1). The cAMP-activated currents were largely (>84%) inhibited by
25 the CFTR inhibitor DPC (500 μ M) as expected for wild type CFTR. Similar results were obtained with WT1 cells, over-expressing wild type CFTR in the same cellular background. The treated $\Delta 508$ cells (10/12) displayed PKA and ATP activated 10-12 pS Cl^- channels (Fig. 2) not observed in the control $\Delta 508$ cells (0/24).

When the CF4/CF6 annealed duplex was, however, added to the tissue culture cells
30 without performing a first oligonucleotide treatment step as described above, phenotypic

reversion was likewise found, as determined by the patch clamp technique. A one step phenotypic reversion technique was chosen as a simpler model for the sequencing studies described below.

Surprisingly, CF4/CF6 cells sporadically showed large, DPC inhibitable whole-cell currents in the absence of cAMP simulation (data not shown). Both WT1 and CF4/CF6 treated $\Delta 508$ cells responded with a comparably similar change in SPQ fluorescence in response to cAMP stimulation (Fig. 3) [Ram et al., (1989) Proc. Natl. Acad. Sci. USA 86, 10166-10170]. Control $\Delta 508$ cells showed no cAMP-induced change in SPQ fluorescence (Fig. 3). The data indicate that CF4/CF6 treatment of $\Delta 508$ cells restores a normal tissue culture phenotype, consistent with the presence of functional CFTR.

Example 2. Sequencing analysis of PCR products.

In order to determine the extent of restored phenotype in the CF4/CF6 treated $\Delta 508$ cells, total RNA was isolated and CFTR specific primers were used to amplify the predicted region. CFTR wild type specific primers efficiently amplified single bands of the expected size in the CF4/CF6 oligonucleotide treated cells. The sequence region after this treatment did not show changes in the PCR amplified oligonucleotides when wild type primers were used. Because the number of $\Delta 508$ mRNA copies that are potentially repaired may be low, allele specific primers for either wild type or mutated CFTR were used next (CFFW and CFFM, Table 1).

Allele specific primers detected mRNA from serial dilutions of wild and $\Delta 508$ total RNA by means of a shift of the amplified band (Fig. 4). Wild type RT-PCR product could be detected in 1:10,000 dilutions in $\Delta 508$ mRNA background (Fig. 4). Initially, RT-PCR product from the allele specific wild type primer (CFFW, Table 1) in the oligonucleotide treated $\Delta 508$ cells also failed to detect insertion in the amplified band. Therefore, total RNA of CF4/CF6 treated $\Delta 508$ cells was further tested by PCR analysis with ARMS specific primers (Fig. 5) [Skerra, (1992) Nucleic Acid Res. 20, 3551-3554]. Wild type and mutated ARMS primer-amplified PCR bands were examined by DNA sequence analysis. The sequence of the amplified mutated cDNA showed a variety of one-codon insertions, rich in G residues. Whether a GGG codon (glycine) is an acceptable substitute for phenylalanine remains to be determined, since systematic study of such base insertion has not been done to our knowledge.

To analyze this observation further, the PCR products were subcloned in pCR-Blunt vector and subjected to DNA sequence analysis. The fraction of control RNAs isolated from

untreated $\Delta 508$ cells showed no oligonucleotide insertion. However, mRNA isolated from CF4/CF6 treated $\Delta 508$ cells showed 20-30% UGU insertion, based on analysis of the percentage of subclones showing TGT insertion into the RT-PCR generated $\Delta 508$ DNA. This percentage of insertion is apparently sufficient for phenotypic reversion in the tissue culture system. None of the subcloned untreated $\Delta 508$ cells displayed false positives (three-base insertion) in the region flanking the initial deletion (Fig. 6). Combined reverse transcription and PCR were performed with forward wild type (NF1) and mutant (MF2), and reverse (CFR) primers (0.5 μ g each) separately. Insertion of bases in the proper position (Scheme 1B) has been found in subcloned and sequenced RT-PCR products, from treated but not control $\Delta 508$ cells.

Without being limited by any particular mechanism, the hypothesis was tested as to whether base insertion in the treated $\Delta 508$ cells has occurred at the RNA level. It was possible that the repair mechanism was carried out instead of/or in addition to, the DNA level, by way of reverse transcription extending back to the genome. This was tested by RT-PCR analysis of DNA from subcloned $\Delta 508$ cells originally treated with CF4/CF6. No evidence was obtained that the restored phenotype was carried back to the inheritable DNA genome level was obtained. Western blot analysis was conducted with antibodies targeted to epitopes upstream and downstream of the $\Delta 508$ deletion, respectively. The data indicate that the full-length protein was made in the presence of the oligonucleotides (data not shown).

Further, the data rule out that partially degraded protein was being translated after treatment with the oligonucleotides because of stop codon missing signals in the treated mRNA [Bedwell et al., (1997) *Nature Med.*, 3, 1280-1284]. Both antibodies showed the same level of protein, without shorter, truncated or degraded peptides. Thus, treatment with CF4/CF6 does not act as an inhibitor of protein synthesis.

Example 3. Mechanism of insertion.

As an initial step, restoration was sought of the most common CF phenotype by antisense oligodeoxynucleotide hybridization to the region immediately adjacent to the trinucleotide deletion, on both sides of the $\Delta 508$ CFTR mRNA. The double-stranded synthetic 2'-O-methyl-RNA/unmodified-RNA oligonucleotide chimera (CF4/CF6) was constructed and used to anneal, selectively cut, and repair the missing region (Scheme 1B). This duplex, as shown, contains a single stranded 2'-O-methyl-substituted 33-mer oligoribonucleotide (CF4) hybridized to an

unmodified 11-mer oligoribonucleotide with 5' and 3' monophosphate termini (CF6). The role of the 5'- and 3'- phosphate termini of CF6, if any, remains to be determined. The CF4/CF6 chimera may theoretically hybridize with the mRNA bearing the deletion (Scheme 1B), followed by an mRNA cleavage step, as a result of which CF6 might theoretically be spliced into this region or alternatively, serve as a triplex backbone sequence for a one-by-one insertion mechanism.

Although insertion of missing bases in the deficient mRNA was found, as shown supra, the specific molecular mechanism is uncertain. Without being limited by any particular mechanism, the mismatch created by using the oligonucleotides provided herein and found immediately proximal in the 5'-direction to the $\Delta 508$ mRNA UUU deletion may induce an as yet unknown deletion mechanism. For one, the deletion step may be induced by either a new enzyme or by the Dicer enzyme. Another possibility is that RNase H, in the presence of a triplex, may induce the deletion. There may conceivably be a deletion in RNA analogous to the MutS DNA mismatch mechanism [Wang et al., (2003) Proc. Natl. Acad. Sci. USA 100, 14822-14827]. The process by which CF4/CF6 restores the phenotype is consistent with specific docking and cleavage of selective nucleotide sequences hybridized to an mRNA sequence. A -TTT- insertion into the PCR amplified deoxyoligonucleotide would be expected, if the -UUU- from CF6 had been inserted into the $\Delta 508$ mRNA. However, TGT (UGU in the $\Delta 508$ mRNA) insertion was consistently observed in clones obtained by ARMS primers amplification RT-PCR products (Scheme 1B and Fig. 6). This finding suggests a one-by-one insertion mechanism, with a G in place of a U.

Initial sequencing of RT-PCR oligodeoxynucleotides obtained with ARMS primers specific for the CFTR wild type sequence (N1, Table 1) revealed the presence of a mixture of residues rich in G's in the $\Delta 508$ site. Subcloning of this oligodeoxynucleotide band resulted in the finding that some but not all of the sequenced cDNA material expressed a TGT at this $\Delta 508$ site. Since it was mRNA that was subjected to RT-PCR amplification, the corresponding bases in the $\Delta 508$ region were actually UGU. The G residue in the UGU could be accounted for by a restoration mechanism with other than Watson-Crick complementarity in insertion [Yang et al., (2003) Proc. Natl. Acad. Sci. USA 100, 15376-15380]. The 3' hybridization initial steps enabled by the ARMS primers may also be flawed by exonucleotide-induced primer degradation in the reverse transcriptase step of the RT-PCR amplification procedure [Skerra, (1992) Nucleic Acid

Res. 20, 3551-3554; Smith et al., (2003) Proc. Natl. Acad. Sci. USA 100, 15440-15445]. Other possibilities of error introduction [Kobayashi et al., (1990) Am. J. Hum. Genet. 47, 611-615], may explain the apparently artifactual deletions shown in Scheme 1B which accompany insertions. This consideration was partially confirmed by wild type ARMS primer-RT-PCR product amplification of the sequence in WT1 cells, which only carries wild type CFTR. In this reaction, the expected -TTT- was found by sequence analysis of the wild type RT-PCR material, in contrast to the TGT (actually UGU in mRNA) when the repaired $\Delta 508$ mRNA was sequenced.

For further clarification of the above results, new sets of primers were constructed with an initial phosphorothioate substituted nucleotide in the 3' end, followed by several (PO) standard nucleotides. This improved primer selectively amplified CF4/CF6 treated, but not control (untreated) RT-PCR product in $\Delta 508$ cells. The ARMS forward PS primer (SNF1) inserts UGU without a concomitant new deletion (Scheme 1B, Table 1), thus presenting the best case for phenotypic reversion to wild type. Just 5' to the UUU in the wild type CFTR is a C residue, while in the mutant $\Delta 508$ CFTR this residue is a U. This may conceivably result in replacement failure 5' to the inserted UGU using the ARMS reverse primer (N1). The purpose in using CF4/CF6 complex, which has a G residue rather than U proximal to the 5' end of the $\Delta 508$ deletion, was to make this residue complementary to that in the wild type sequence rather than in the deleted $\Delta 508$ sequence. Both AUC and AUU code for isoleucine. This base mismatch for the $\Delta 508$ mRNA (CF Scheme 1) may however induce a single strand break, analogous to that found for single DNA mismatches as mentioned above [Wang et al., (2003) Proc. Natl. Acad. Sci. USA 100, 14822-14827], necessary for a subsequent repair mechanism to be initiated. This eliminates the possibility that the change of C to a U, immediately 5' to the TTT in the same position in the $\Delta 508$ gene may contribute, in addition to the $\Delta 508$ TTT deletion, to the phenotypic change in CFTR.

DNA polymerase has a high degree of Watson-Crick fidelity in synthesizing complementary strands. Reverse transcriptase, which starts at the 3'-end of the PCR amplification, however, has a lower level of this specific type of fidelity. This property of reverse transcriptase may be a possible explanation for the UGU (the equivalent of TGT) found in the amplified, restored $\Delta 508$ mRNA. In relation to phenotypic restoration, benign mutations of the TTT present in the wild type gene do exist. TGT is one of these, coding for cysteine, which appears to be an acceptable substitute for phenylalanine in the $\Delta 508$ region [Kobayashi et al.,

(1990) Am. J. Hum. Genet. 47, 611-615]. The 2'-O-methyl group, plus the 5-methyl of thymidine, which uridine does not have, may also alter the tertiary structure of the CF4 chimera. Such factors may influence the nucleophilicity, electrophilicity, and polarizability of the bases, which make up the mRNA-CF4/CF6 triple-stranded structure. Tinoco and colleagues have described numerous double stranded DNA/RNA base complementarities which conformational and other experimental molecular conditions may cause to favor over the standard Watson-Crick AT and GC ones [Burkard et al., (1999) *In* The RNA World. editors. Cold Spring Harbor Lab. Press, New York. 675-680]. The highly sensitive nanosphere/gold procedure of Letsinger and colleagues [Taton et al., (2000) Science, 289, 1757-1759; Letsinger et al., (2000) Bioconj. Chem. 1, 289-291] may in the future be applicable as an alternative to the PCR technique, avoiding possible artifacts introduced by PCR amplification, or else may be used following subcloning.

The data herein indicate that specific base insertion in $\Delta 508$ mRNA has been made. Certain PCR-introduced artifacts have been avoided by phosphorothioate modification of the 3'-terminal residues of ARMS specific primers. Under our best conditions thus far, insertion of UGU has taken place in a sufficient fraction of $\Delta 508$ mRNA to induce phenotypic but not genotypic reversion in a tissue culture cell line. The subcloning data shown 20-30 percent insertion of UGU in the site of the $\Delta 508$ mRNA UUU triplet deletion.

Example 4. Therapeutic application

Suitable genetic diseases and sequences of appropriate targets in genes are shown in Tables 10-30. Using the sequence information and the methods provided herein, one may design oligonucleotide complexes to treat a cell carrying a mutation having a sequence shown herein, and treat the disease associated with the mutation.

What is claimed is:

1. A method for targeted gene repair, comprising

contacting a target RNA of a cell with a hybrid DNA/RNA oligonucleotide complex, said
5 complex comprising a first strand and a second strand, said first strand comprising a flanking
sequence complementary to said target RNA and central sequence comprising at least one non-
complementary nucleotide in a location opposite a defect of said target RNA, wherein said
flanking sequence of said first strand comprises an RNase H-resistant modification 3' and 5' to
said nucleotide, said first strand and said second strand being annealed; and

10 hybridizing said complex to said target RNA, wherein a repaired RNA is produced, said
RNA comprising a sequence alteration opposite said defect of said target RNA, wherein said
genomic target DNA sequence is unaltered.

2. The method of claim 1, wherein said second strand is shorter than said first strand.

3. The method of claim 1, wherein said first strand and said second strand are of equal length.

4. The method of claim 1, further comprising contacting the target RNA with a
phosphorothioate (PS) containing sequence of a deoxynucleotide with RNase H resistant
20 flanking ends.

5. The method of claim 4, wherein following contacting the target RNA with a phosphorothioate
(PS) containing sequence, treating the target RNA with annealed hybrid oligonucleotide
complex, wherein a repaired RNA is produced..

6. The method of claim 1, wherein said alteration is not maintained in a progeny of said cell.

7. The method of claim 1, wherein said defect is a substitution, deletion, or addition of at least
one base pair compared to a normal wild type sequence.

8. The method of claim 1, wherein said RNase H-resistant modification is the addition of a 2-O-methyl moiety.

5 9. The method of claim 1, wherein at least one nucleotide of said flanking sequence 3' to said oligonucleotide hybridizable to the target and at least one nucleotide of said flanking sequence 5' to said oligonucleotide hybridizable to the target comprise said RNase H-resistant modification.

10 10. The method of claim 1, wherein said first strand comprises an RNase activating oligonucleotide comprising a phosphorothioate linkage flanked by RNase H resistant segments.

11. The method of claim 1, wherein said first strand is at least 10 nucleotides in length.

12. The method of claim 1, wherein said first strand comprises at least 11 nucleotides.

15 13. The method of claim 1, wherein said flanking sequence of said first strand comprises at least two nucleotides.

14. The method of claim 1, wherein said second strand comprises at least 7 nucleotides.

20

25

30

Table 1. Sequences of oligonucleotides used (5'>3')

CF4	uuu cuu uua uag uag aaa cca caa agg aua cua (SEQ ID NO: 4,340)
CF6	pC AUC UUU GGU Gp (SEQ ID NO: 4,341)
F1	GGG AGA ACT GGA GCC TTC A (SEQ ID NO: 4,342)
5 N1	GTA TCT ATA TTC ATC ATA GGA AAC ACC ACA (SEQ ID NO: 4,343)
M1	GTA TCT ATA TTC ATC ATA GGA AAC ACC ATT (SEQ ID NO: 4,344)
NF1	GCC TGG CAC CAT TAA AGA AAA TAT CAT CTT (SEQ ID NO: 4,345)
MF2	GCC TGG CAC CAT TAA AGA AAA TAT CAT TGG (SEQ ID NO: 4,346)
CFR	GTT GGC ATG CTT TGA TGA CGC TTC (SEQ ID NO: 4,347)
10 CFFW	GGC ACC ATT AAA GAA AAT ATC ATC TT (SEQ ID NO: 4,348)
CFFM	GGC ACC ATT AAA GAA AAT ATC ATT GG (SEQ ID NO: 4,349)
SCFR	GTT GGC ATG CTT TGA TGA CGC TTC (SEQ ID NO: 4,350)
SNF1	GCC TGG CAC CAT TAA AGA AAA TAT CAT CTT (SEQ ID NO: 4,351)
SMF2	GCC TGG CAC CAT TAA AGA AAA TAT CAT TGG (SEQ ID NO: 4,352)

15

Table 1. Primers and constructs used to repair CFTR mRNA. Lower case letter are a nucleotide sequence in CF4 corresponding to bases of 2'-O-methylribosyl oligonucleotides, with internucleoside phosphate bonds. Upper case letter are a nucleotide sequence in CF6 corresponds to natural RNA sequences and small case p corresponds to the terminal phosphate groups. Bold type corresponds to the natural DNA sequences. Shaded region in SCFR, SNF1 and SMF2 corresponds to internucleoside phosphorothioate bonds.

20

Abstract

Compositions and methods of treatments of cells are provided for altering the phenotype of a cell by administering an oligonucleotide complex to the cell, the complex having two strands
5 and chemical modifications.

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Scheme depicting deletion in $\Delta 508$ mRNA, possible configuration of CF4/CF6 in the hybridization step, and varied replacements which were found.

Δ508 mRNA repair:

5' - AAA GAA AAU AUC AUC UUU GGU UCC UAU GAU - 3' Wild type

5'- AAA GAA AAU AUC AUU GGU GUU UCC UAU GAU-3' Δ508 mRNA

Triribonucleotide $\Delta 508$ genetic deletion

5' - AAA GAA AAU AUC AUG^{CTT} GGU GUU UCC UAU GAU - 3' Δ508 mRNA

3' UUU CUU UUA UAG UAG TCCA CAA AGG AUA CUA 5' CF4

5' pC AUC	GGU Gp 3'	CF6

Varied ribonucleotide insertion and deletion steps, with (c) being the best result:

Repeated Sequence analysis of RT-PCR products with different primers:

(a) ARMS Reverse primer (N1)

5' - AAA GAA AAU AUC A UGU GGU GUU UCC UAU GAU-3'

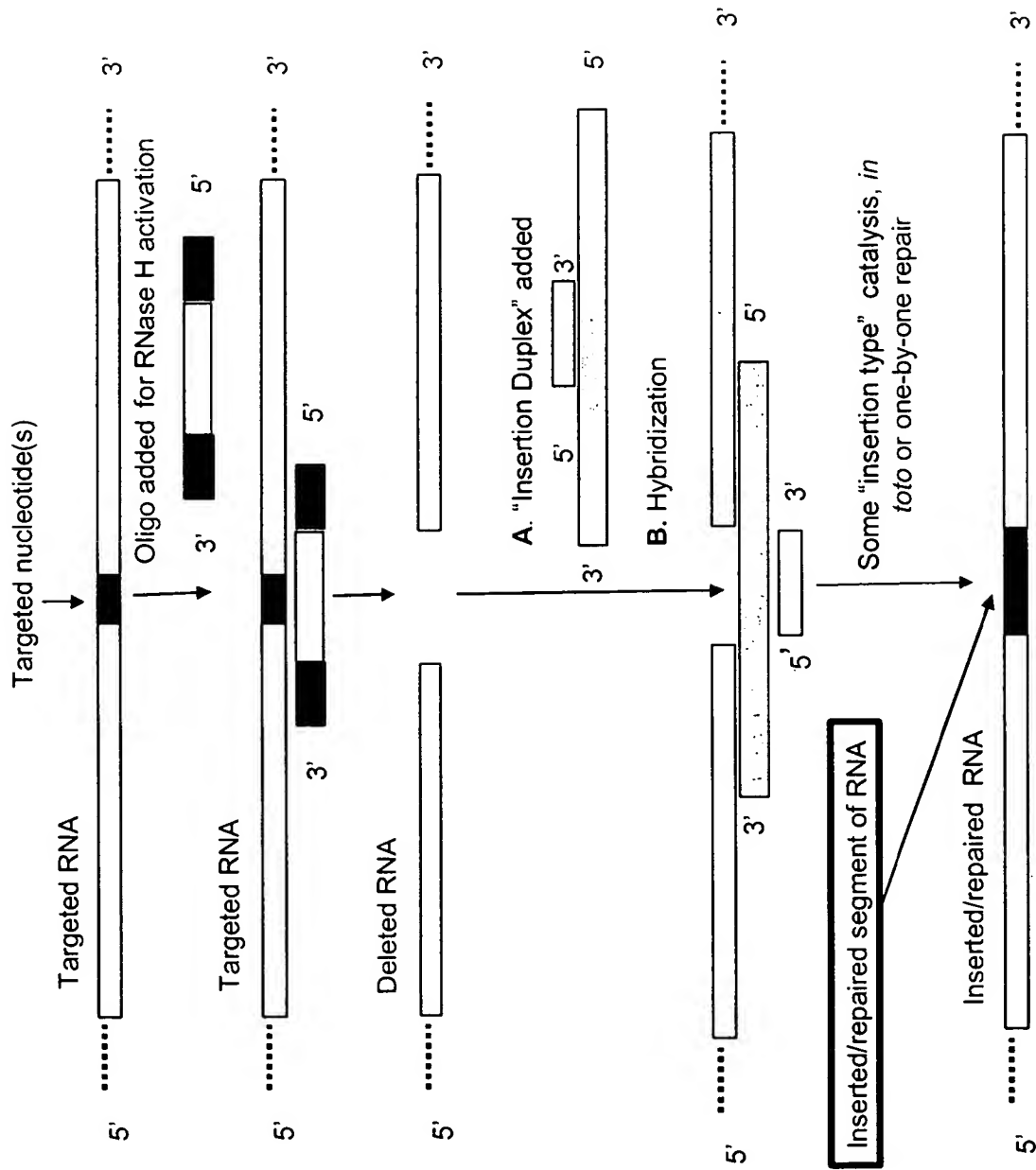
(b) ARMS forward primer (NF1)

5' - AAA GAA AAU AUC AUC UGU GUU UCC UAU GAU-3'

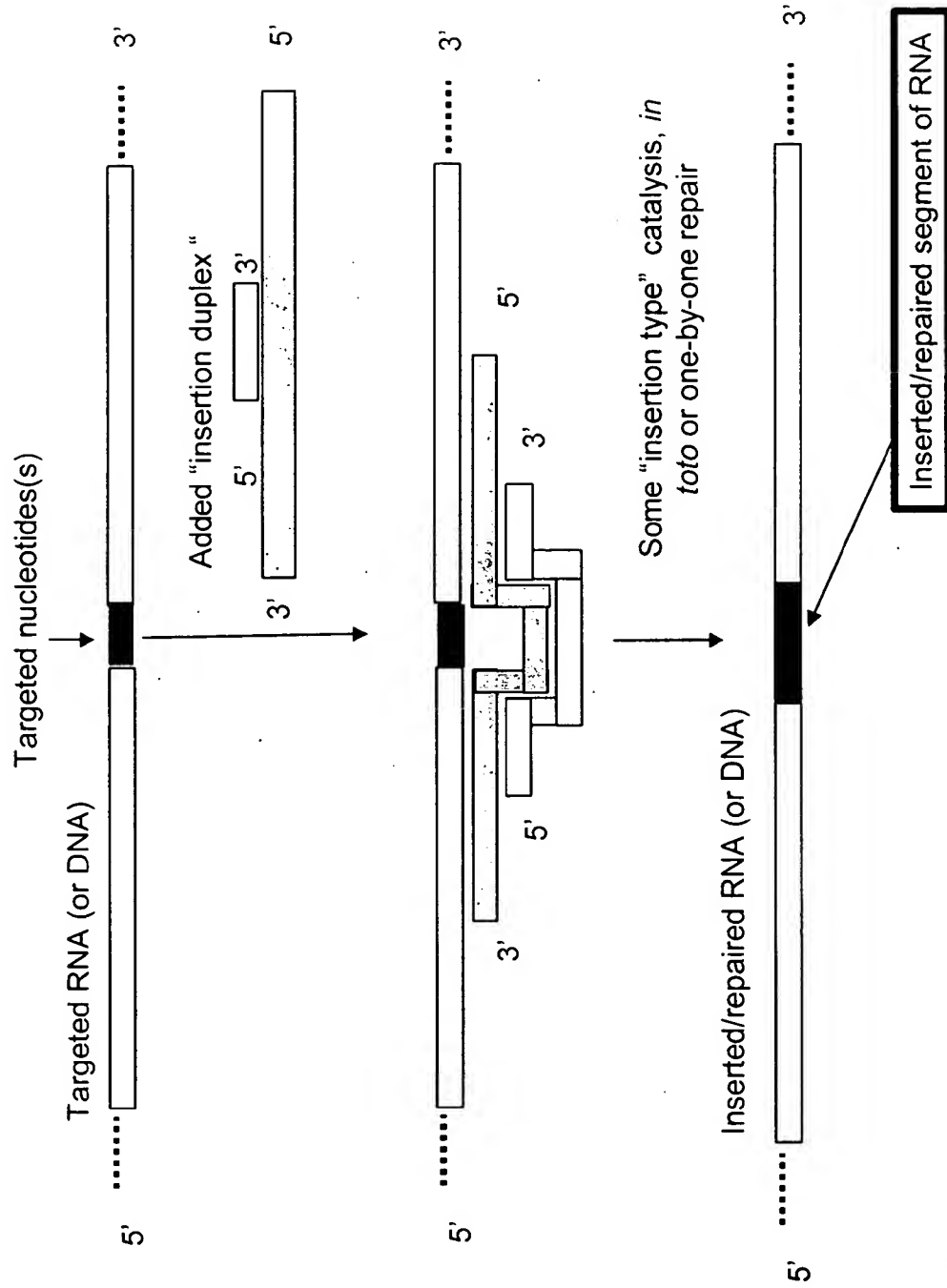
(c) ARMS forward PS primer (SNF1)

5' - AAA GAA AAU AUC AUC UGU GGU GUU UCC UAU GAU - 3'

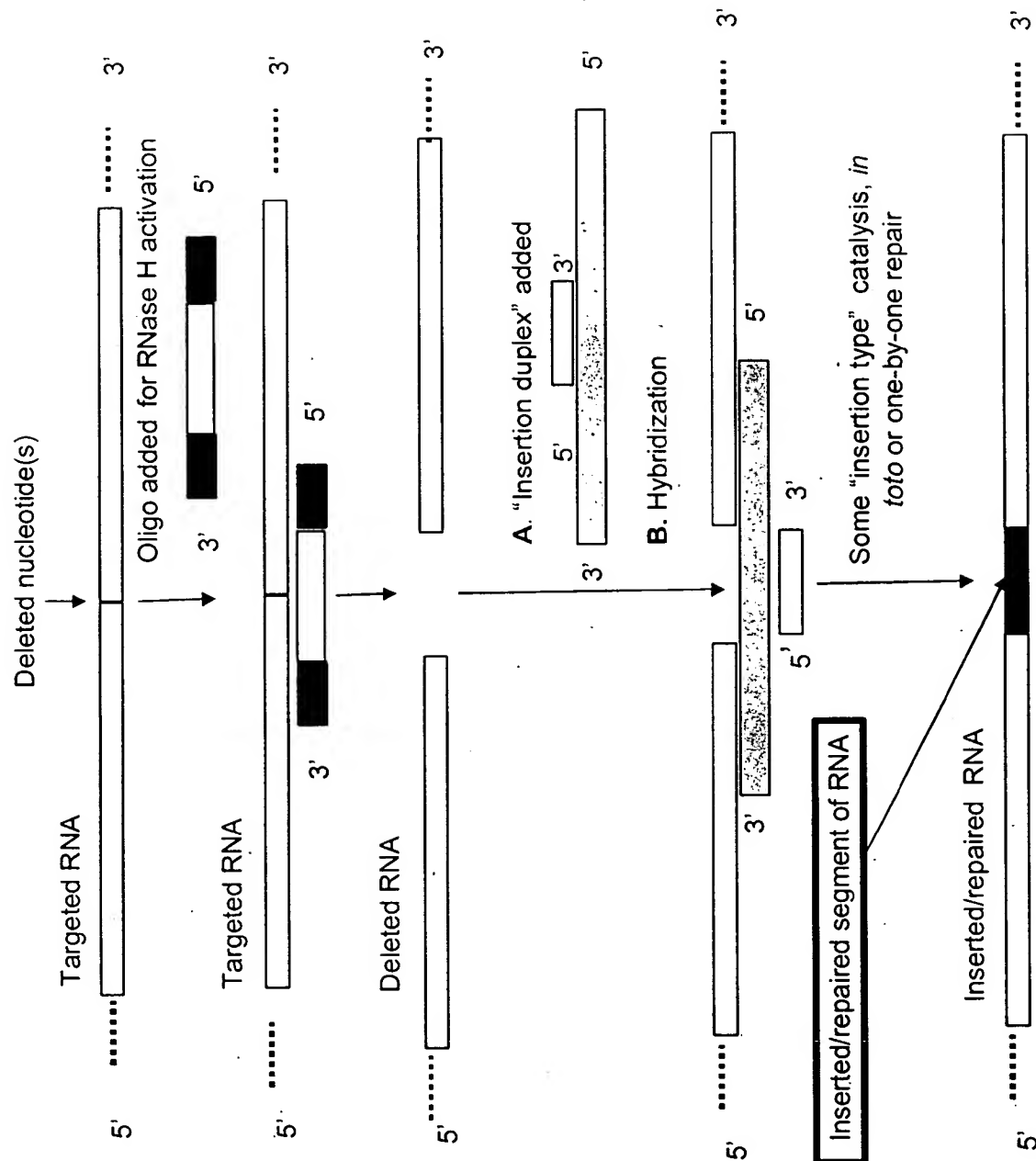
Scheme 1



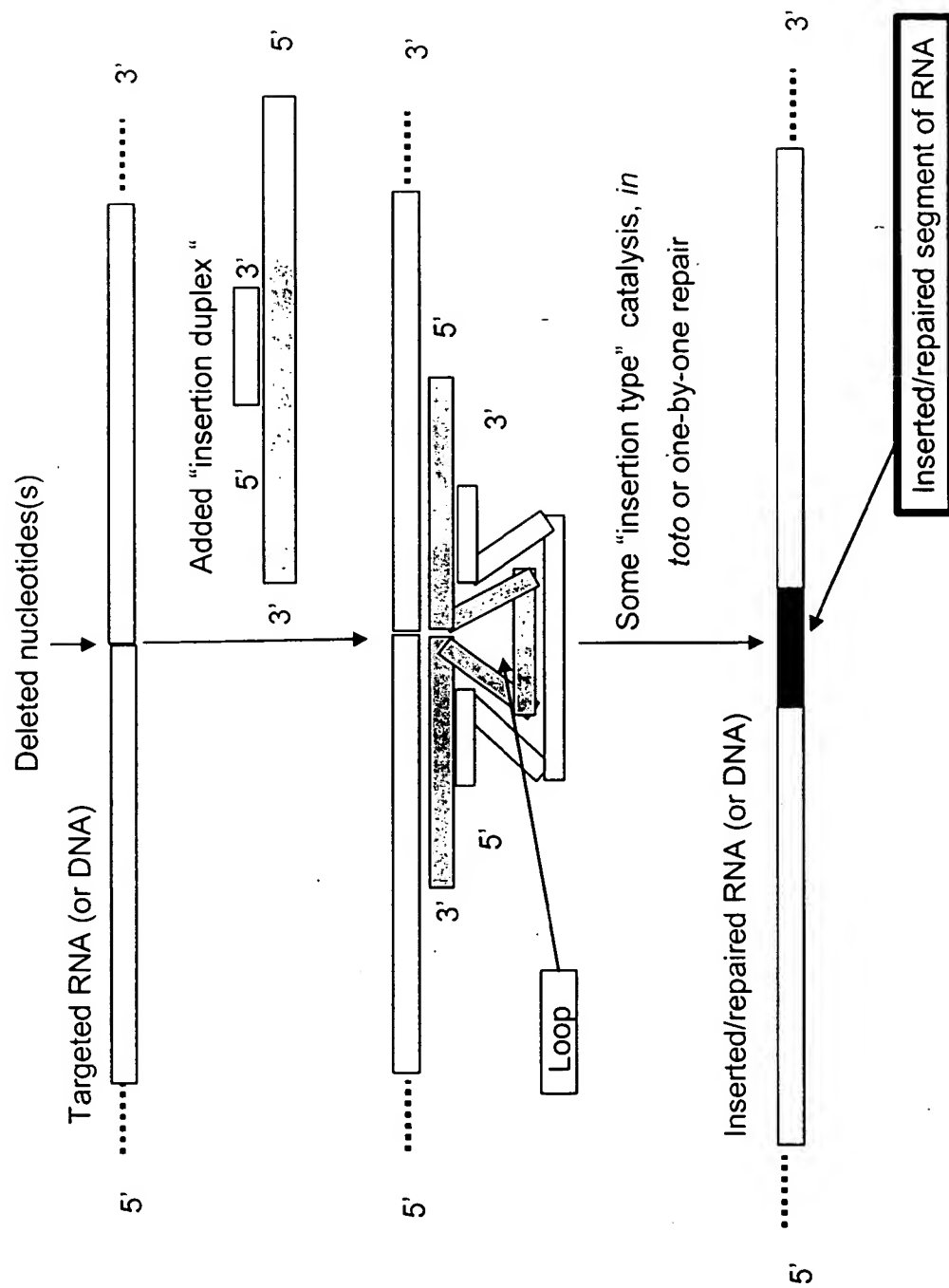
Scheme 2



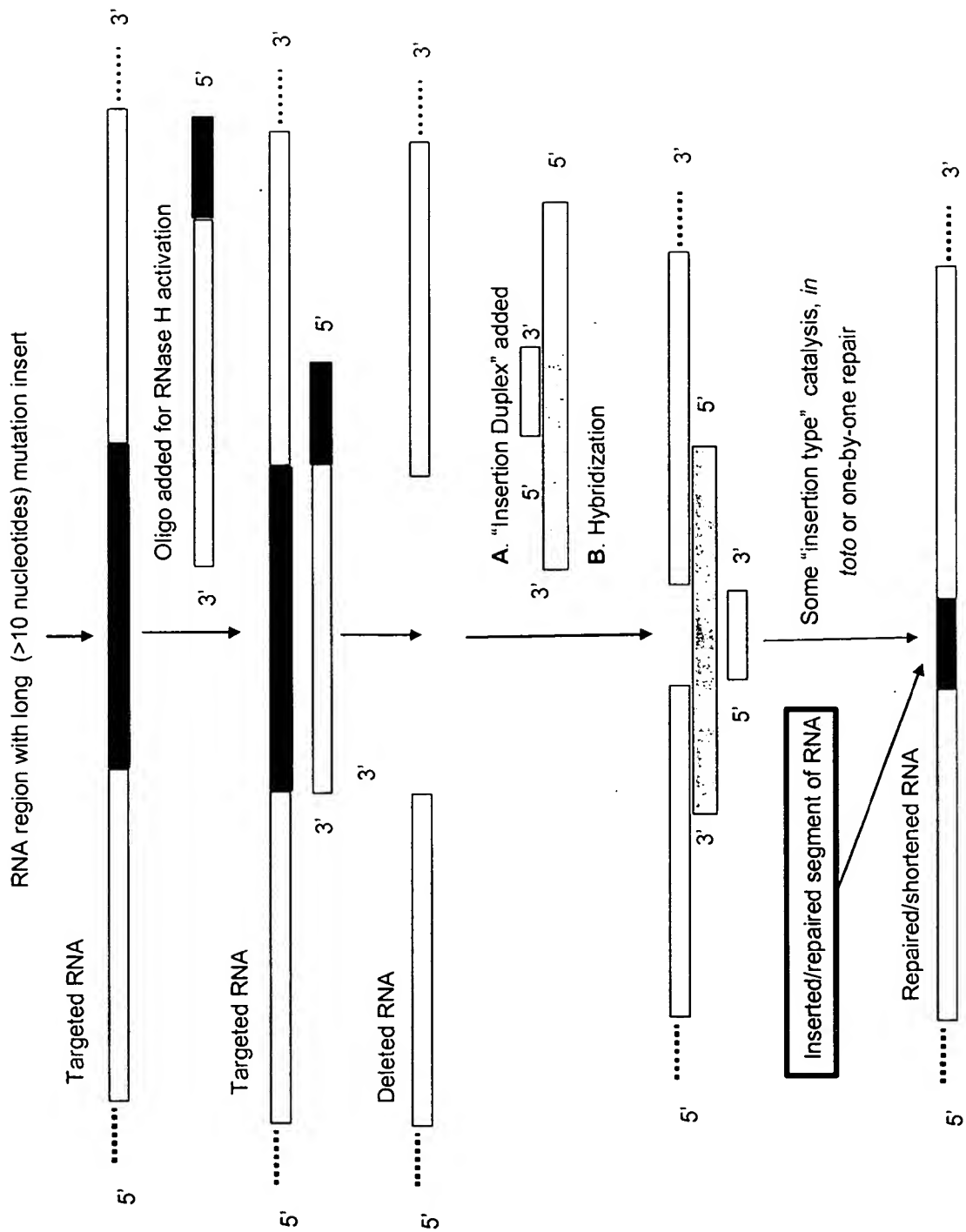
Scheme 3



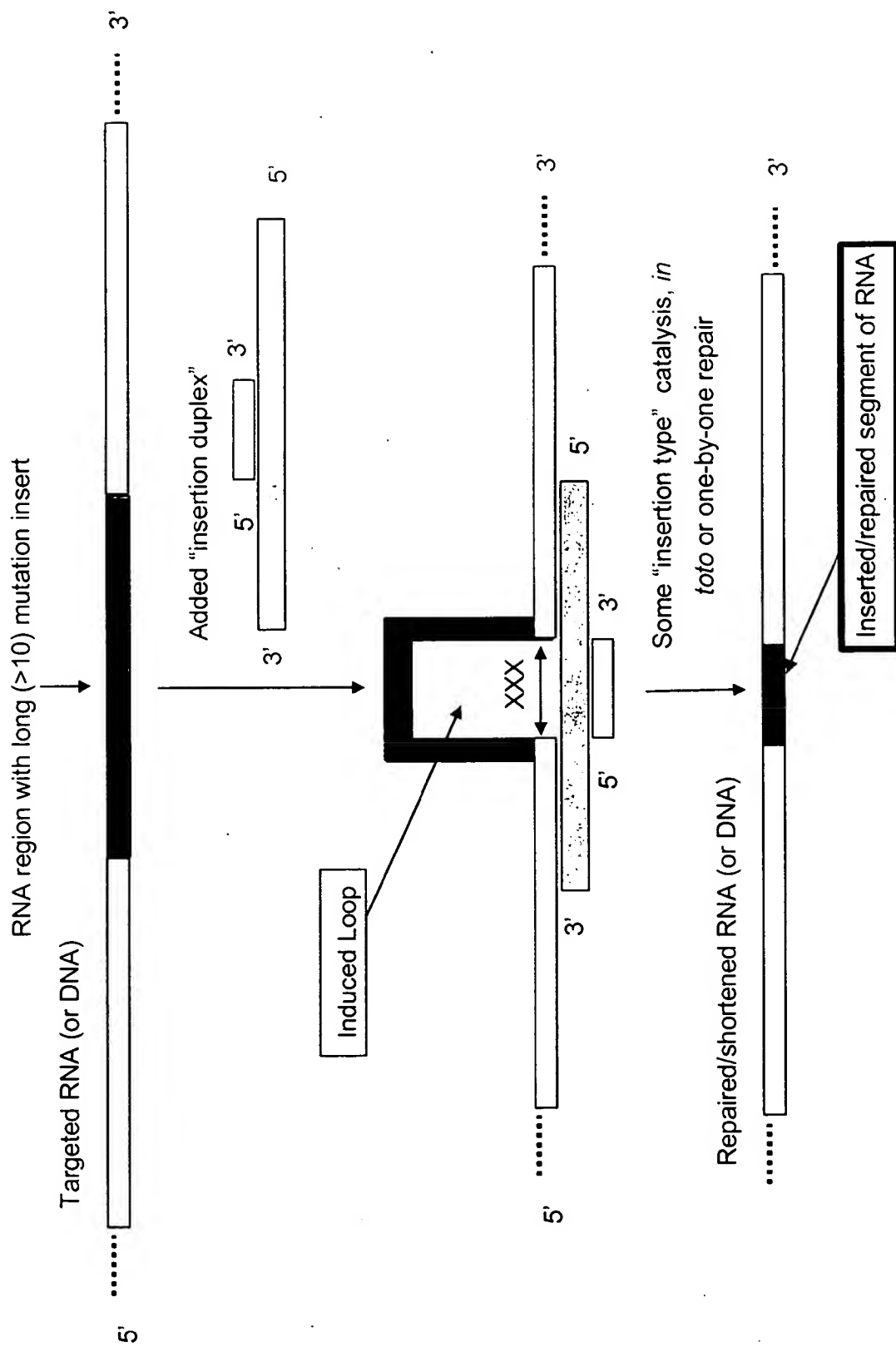
Scheme 4



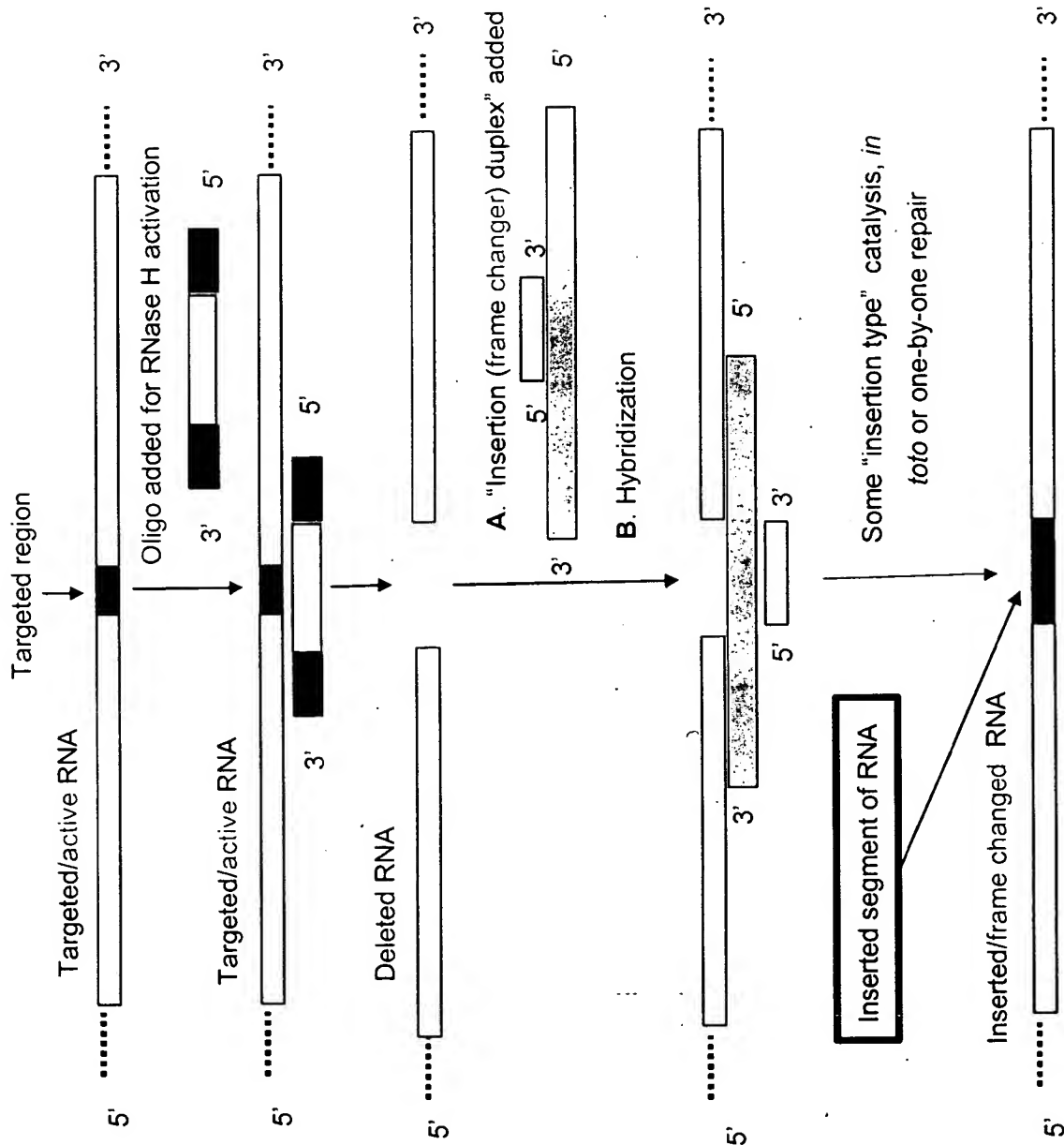
Scheme 5



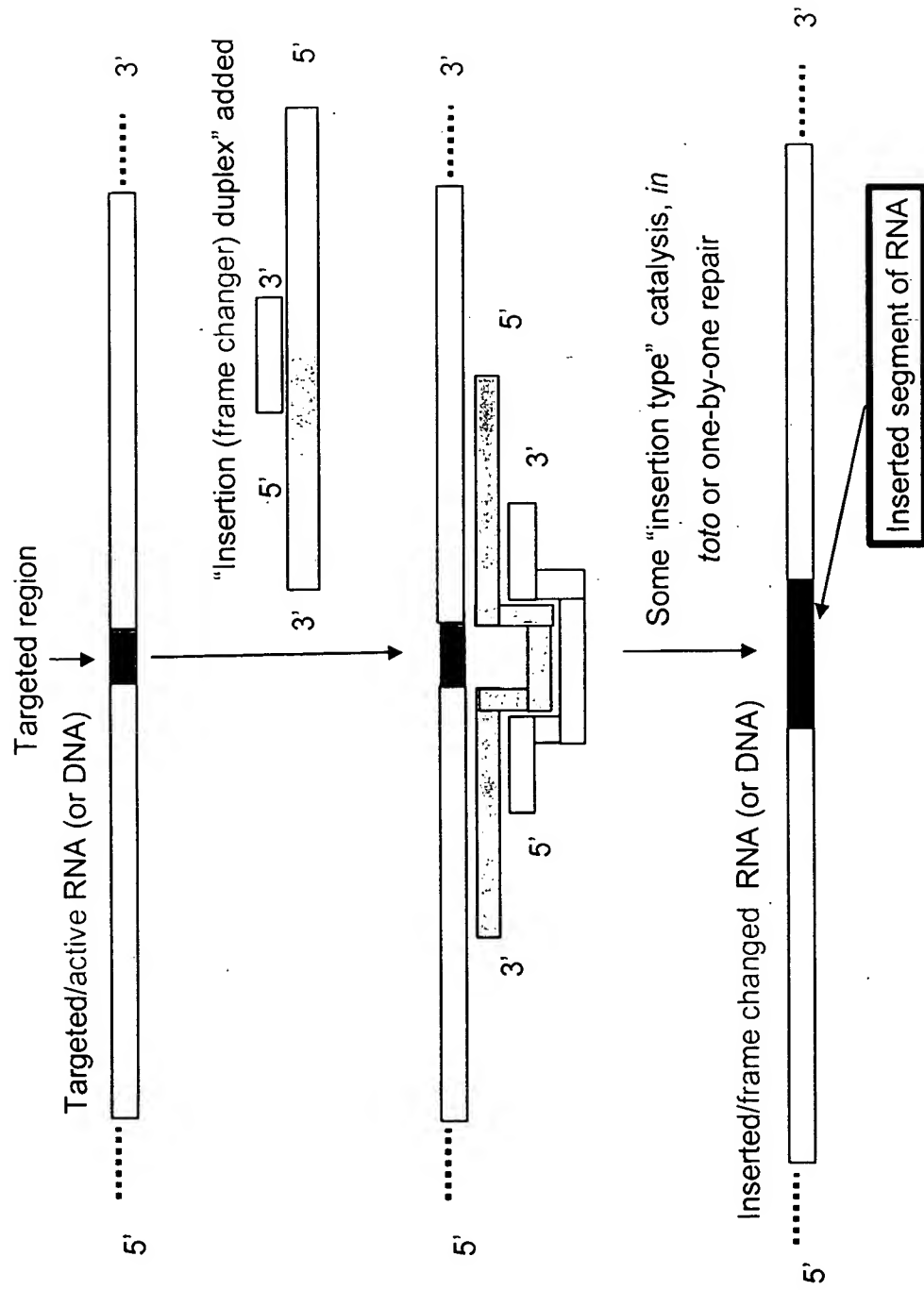
Scheme 6



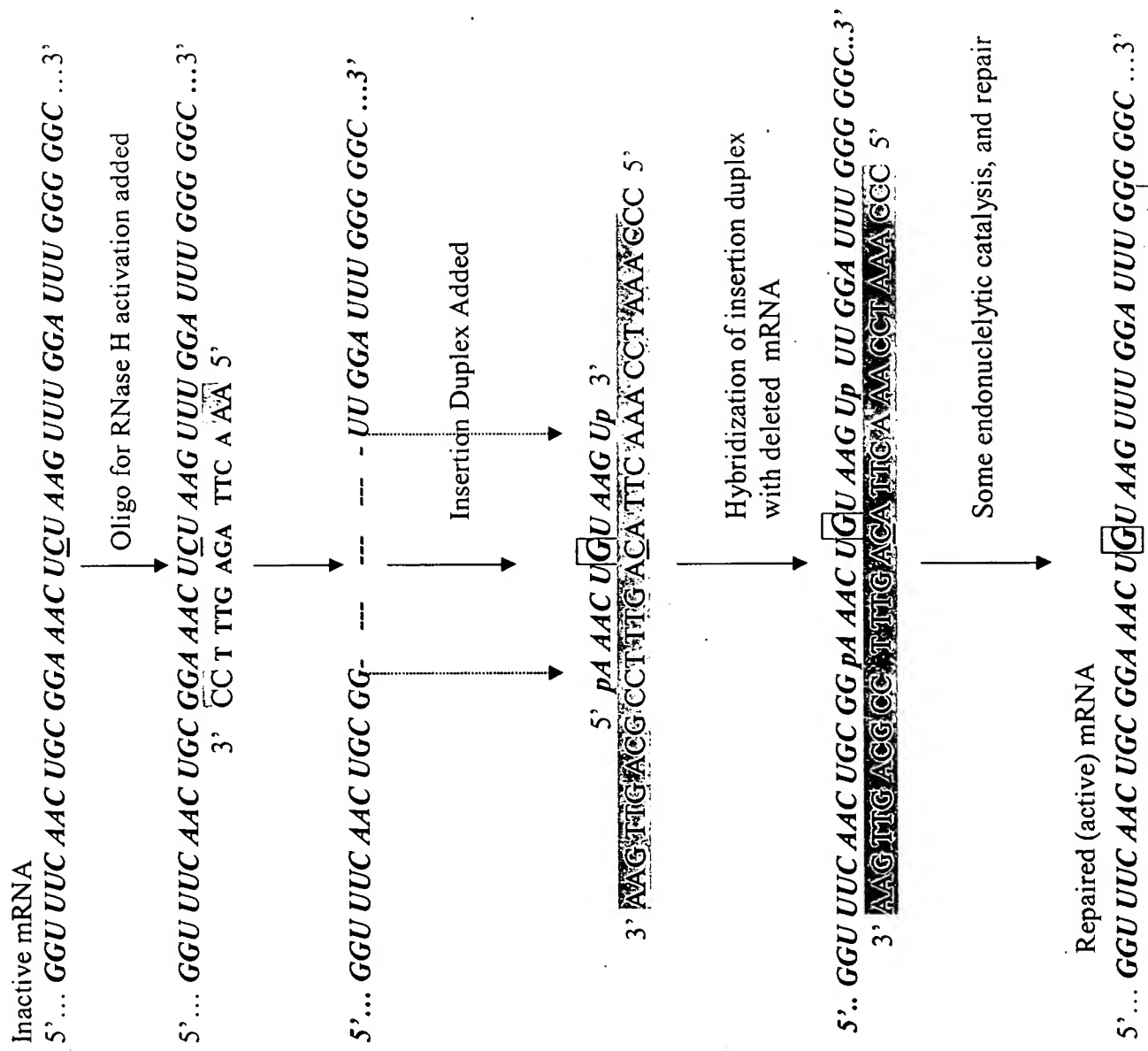
Scheme 7



Scheme 8



Scheme 9



Scheme 11

Inactive mRNA

5' ... GGU UUC AAC UGC GGA AAC UCU AAG UUU GGA UUU GGG GGC ... 3'

Insertion Duplex Added

5' ... GGU UUC AAC UGC GGA AAC U^C U AAG UUU GGA UUU GGG GGC ... 3'

3' AAG TTG ACG CCG CTT TGA A TTC AAA CCG T AAA CCC 5'

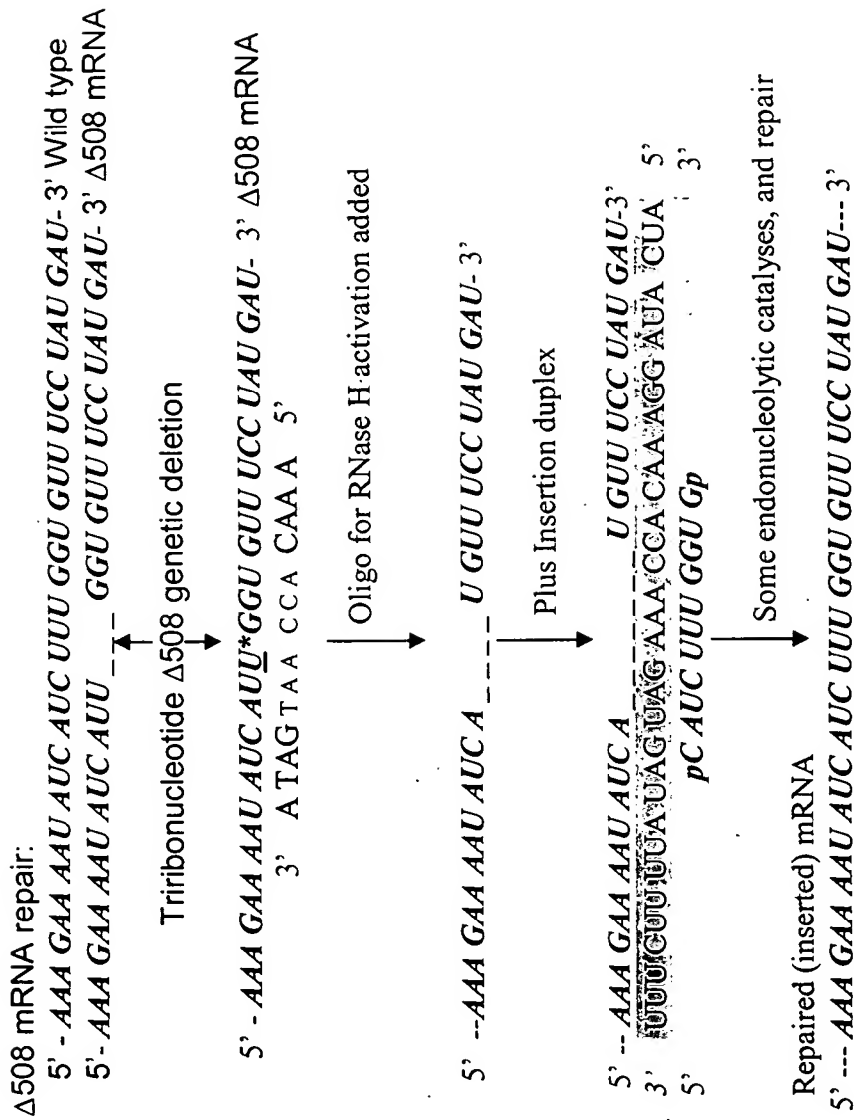
5' pA AAC U UAAG Up 3'

Some endonucleolytic catalysis, and repair

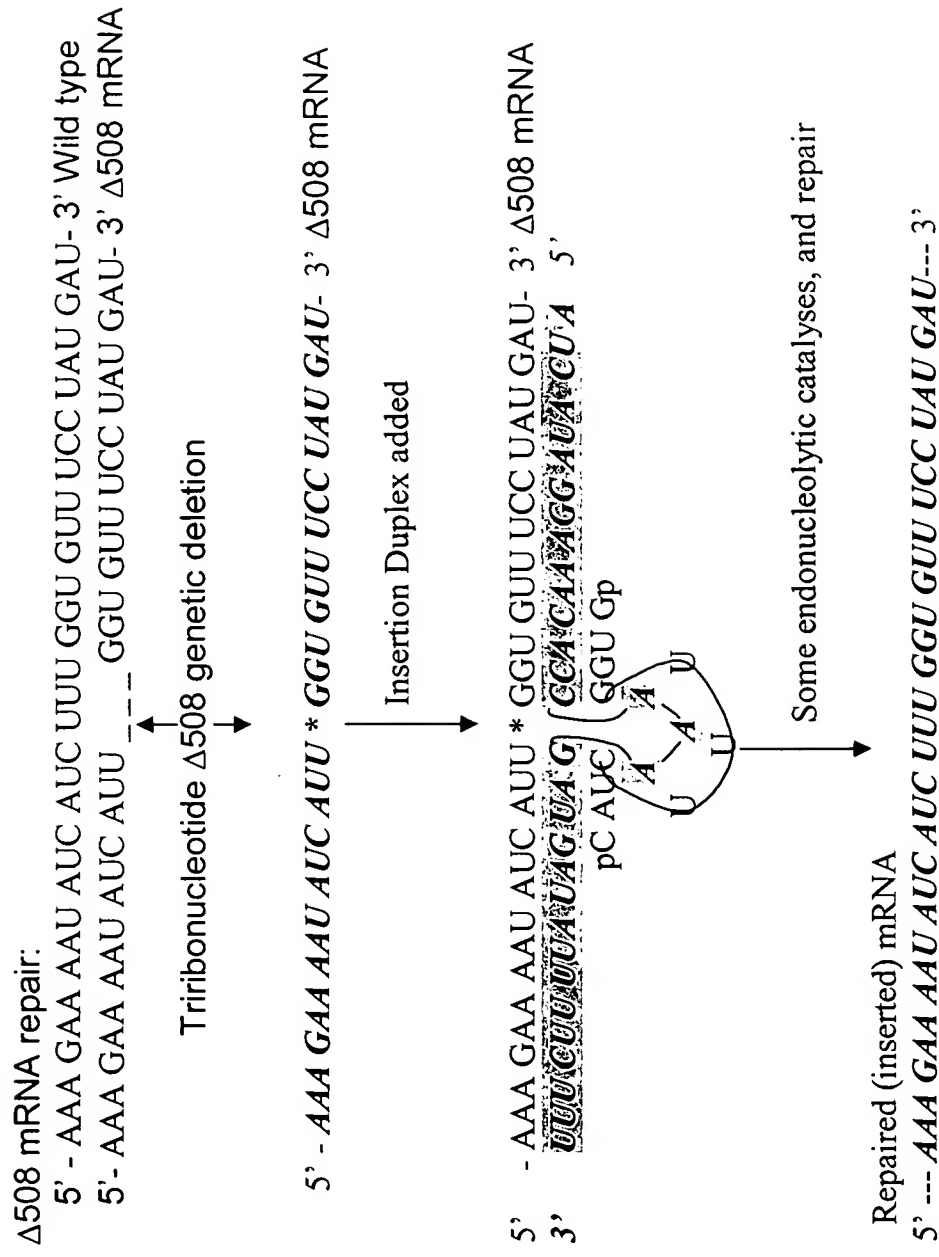
Repaired (active) mRNA

5' ... GGU UUC AAC UGC GGA AAC U^G U AAG UUU GGA UUU GGG GGC ... 3'

Scheme 12



Scheme 13



Scheme 14

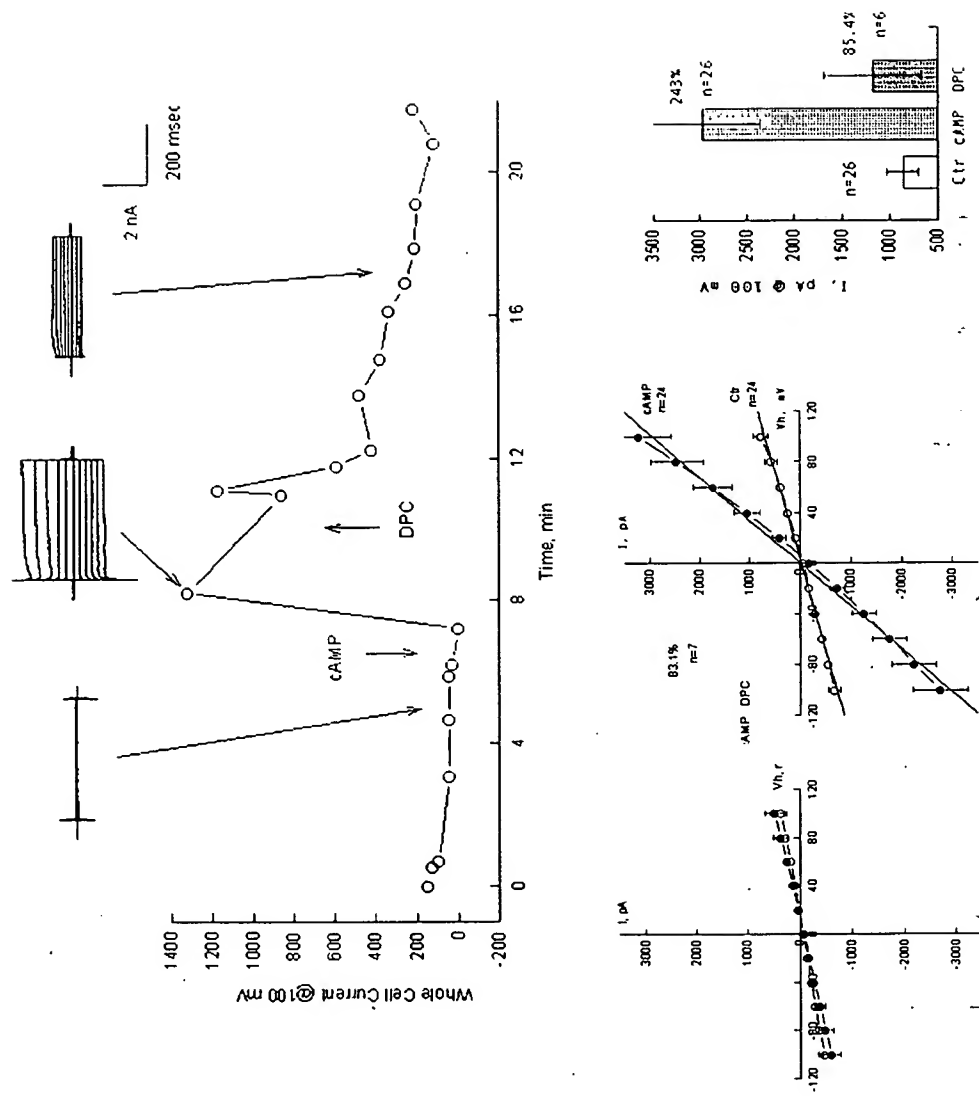


Fig. 1

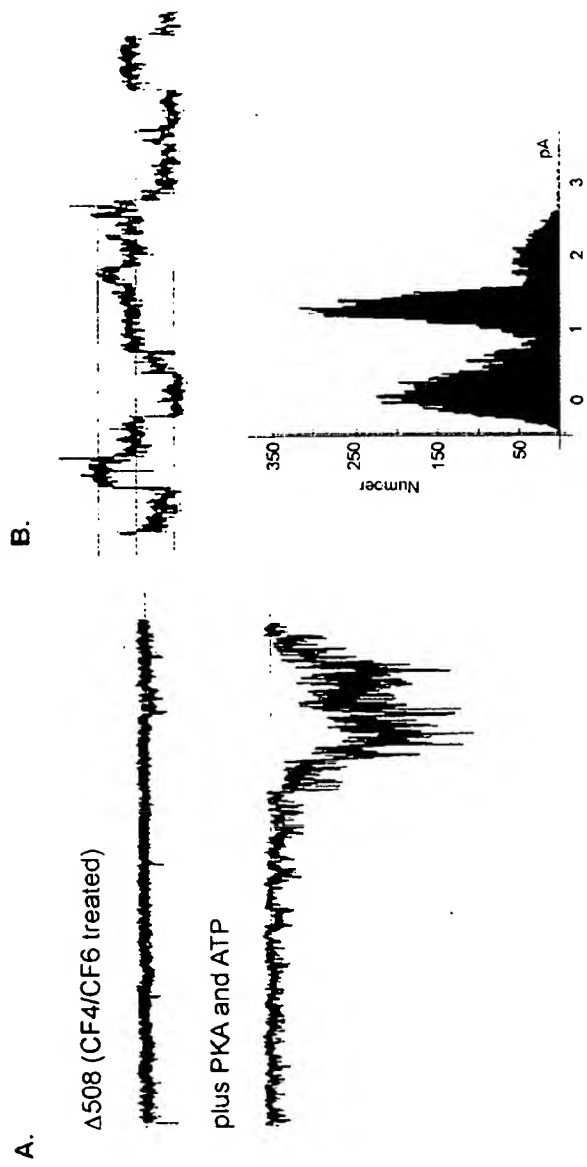


Fig. 2

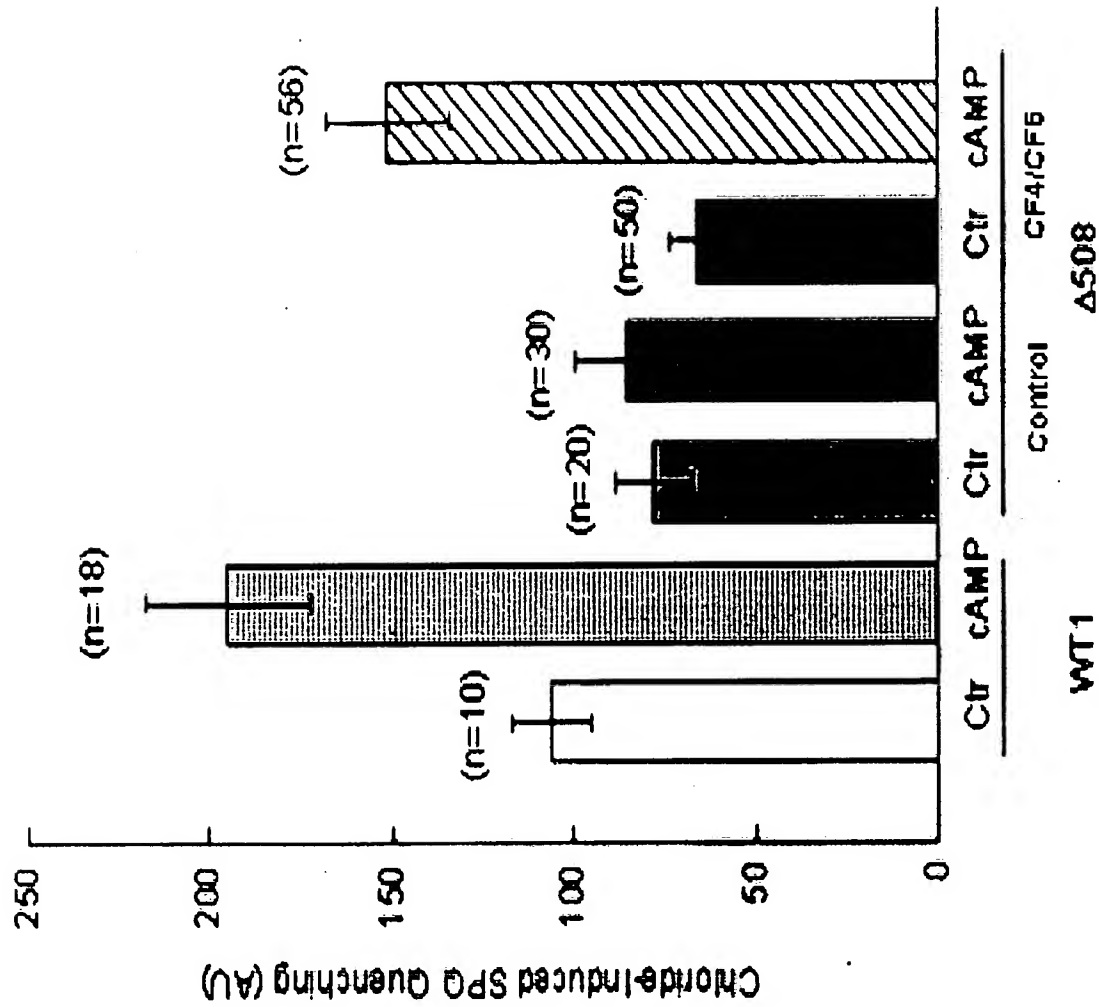


Fig. 3

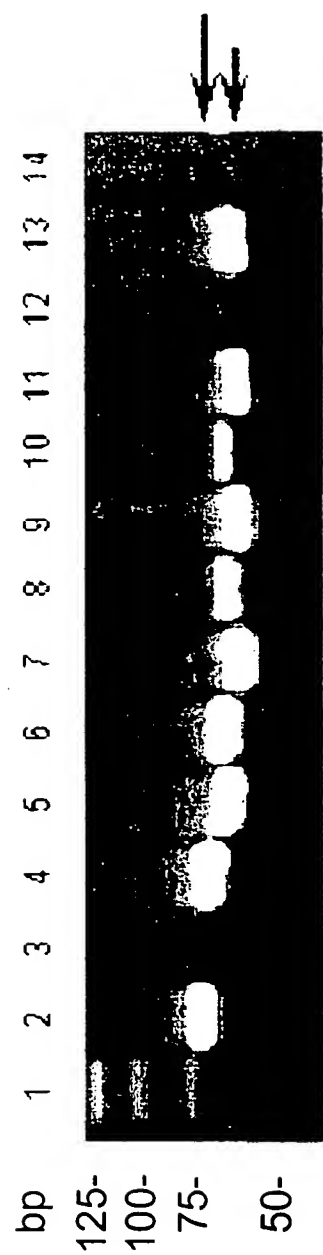


Fig.4

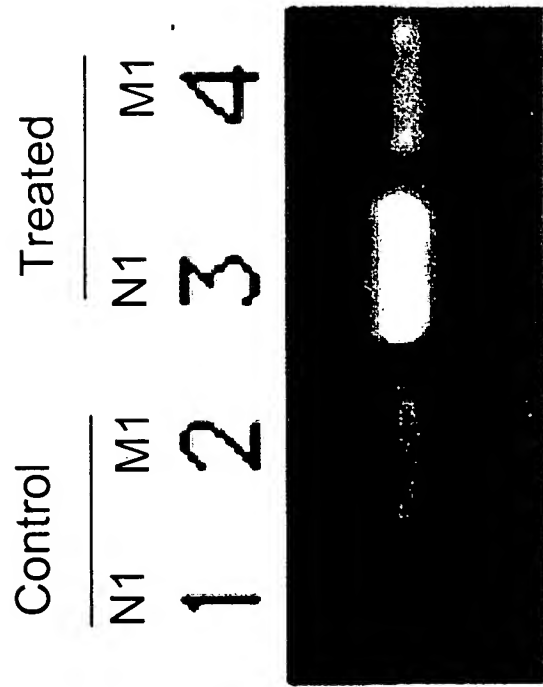


Fig. 5



Fig.6